Metallurgy Department. Progress report for the period 1 January - 31 December 1980

Risø National Laboratory, Roskilde

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Risø National Laboratory, DK-4000 Roskilde, Denmark
July 1981

ERRATA SHEET FOR Risø-R-444

Page 5 Line 21: "12 metres", read "20 metres".

Page 51 1) Abstract for: "Behaviour of Hard and Soft Ions in Solid Electrolytes", see abstract under "Fatigue of Copper Polycrystals at Low Plastic Strain Amplitudes" (page 51).

2) Abstract for: "Fatigue of Copper Polycrystals at low Plastic Strain Amplitudes", see abstract under "Behaviour of Hard and Soft Ions in Solid Electrolytes" (page 51).

Page 53 1) Abstract for: "Densification studies of Ceramic Powder Compacts by Quasi-Isothermal Dilatometry", see abstract under "Materialeegenskabernes betydning for risikoanalyse" (page 54).

2) Abstract for: "Stiffness Based Fatigue Damage Characterization of Fibrous Composites", see abstract under "Densification Studies of Ceramic Powder Compacts by Quasi-Isothermal Dilatometry" (page 53).

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METALLURGY DEPARTMENT PROGRESS REPORT FOR THE PERIOD 1 JANUARY TO 31 DECEMBER 1980

Abstract. The activities of the Metallurgy Department at Risø during 1980 are described. The work is presented in four chapters: General Materials Research, Technology and Materials Development, Fuel Elements, Non-Destructive Testing. Furthermore, a survey is given of the department's participation in international collaboration and of its activities within education and training. A list (with abstracts) of publications and lectures by the staff during 1980 is included.

INIS-descriptors: FUEL ELEMENTS, METALLURGY, NON-DESTRUCTIVE TESTING, RESEARCH PROGRAMS, RISOE NATIONAL LABORATORY.

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1. INTRODUCTION

The time schedule for the establishment of nuclear power in Denmark is still uncertain. Risø is therefore at stand-by in this field but most of the nuclear programmes are continued in order to ensure up-to-date knowledge. In the Metallurgy Department the nuclear work comprises projects within design and testing of fuel elements, fracture mechanics studies in pressure vessel steels and non-destructive testing. The projects concentrate more and more on advanced problems, which in many cases are studied in collaboration with other parties in Europe and in the United States. An example of such programmes is the study of fission gas release in Zircaloy-UO_2 rods after high burn-up. This programme is sponsored by a number of firms and organizations in Europe and abroad. Other examples are dynamic fracture mechanics studies on steel and acoustic emission investigations of welds carried out under the auspices of the European Coal and Steel Community (ECSC).

With respect to alternative energy technology, a major effort was devoted to fibre reinforced plastics, which have been used as a wing-blade material for two 600 kW wind turbines built by a group of electricity generating companies. Six wings with a length of 12 metres are now operating and the fatigue properties of the glassfibre/polyester wing-blade material is being investigated. Other projects within this area are related to the design, manufacturing and testing of wings for small wind turbines. Other energy projects include metal-hydrogen systems (e.g. for transportation and storage of energy) and solid ion conductors for use in rechargeable batteries. These projects are partly carried out under the auspices of EEC, The Nordic Fund for Industrial Development and the Ministry of Energy.

In order to promote generally the fibre materials technology in Denmark a semi-scale fabrication facility has been built with the financial support of the National Agency of Technology. This

facility, which includes a filament winding machine, autoclaves and testing equipment, has already been used rather extensively for industrial contract work outside the energy field.

Work was done under contract for industries and utilities in Denmark and abroad. Due to their proprietary nature, most of these activities are excluded from the present report. Among the major nuclear activities were fuel element development, where collaboration with the Elsinore Shipyard was continued, isotope analysis and post-irradiation examinations of full-scale power reactor rods ($Zr-UO_2$ and $Zr-UO_2-PuO_2$).

Other work on contract was done on high-temperature components for the chemical industry and non-destructive testing. Further projects were centered on the development of materials and processes, in particular ceramics for measurement of oxygen potentials in combustion gases, sintering of nuclear ceramics, and brazing technology. In the field of neutron radiography standardization work was continued together with the neutron radiography working group sponsored by Euratom.

To support the technological programmes of the department a large effort was as usual devoted to fundamental problems, e.g. radiation damage in metals, strength/structure relations in single-phase and two-phase materials and structures in ceramics. A new project (in collaboration with the Physics Department) was to use a standard neutron spectrometer at DR 3 to determine transformation kinetics in materials. Initially, recrystallization kinetics are studied by fast registration of texture changes during annealing of heavily cold-rolled copper. A large part of the fundamental work is carried out in collaboration with universities and research laboratories in Denmark and abroad.

The department participated in international collaboration on specific research projects and also in a number of international projects and study groups under the auspices of the NEA, EEC and various Nordic and US organizations.

The department organized the First Risø International Symposium on Metallurgy and Materials Science, 8-12 September 1980. The title of this symposium was: "Recrystallization and Grain Growth of Multi-phase and Particle Containing Materials". The symposium was attended by 84 participants presenting 45 papers. The department also organized the IAEA's Specialist's Meeting on "Pellet-Cladding Interaction in Water Reactors", 22-26 September 1980. This meeting was attended by 48 participants presenting 31 papers. The planning was started for the Second Risø International Symposium to be held at Risø 14-18 September 1981. The title of this symposium is: "Deformation of Polycrystals: Mechanisms and Microstructures".

Educational activities were continued; students and post-graduates from Denmark and abroad studied in the department.

GENERAL MATERIALS RESEARCH

Bauschinger effect in copper

(in collaboration with the Cavendish Laboratory and the Department of Metallurgy and Materials Science, University of Cambridge)

The Bauschinger effect in pure copper was found to be very small compared with that of dispersion-hardened copper. It is temperature-independent and characterised by a permanent softening which is proportional to the flow stress and by a Bauschinger strain which is proportional to the plastic strain. These observations can be understood in terms of a composite model of the work-hardened material in which dislocation tangles act as hard but deformable inclusions in a soft matrix of relatively dislocation-free material. The composite model is based on etch pit studies and electron microscopical observations. It accounts for the stored energy of cold-work. The model allows reconciliation of two main models of the work-hardened state: the forest model and the pile-up model.

Fatigue phenomena in copper

(in collaboration with the Cavendish Laboratory, University of Cambridge)

The ladder structure characteristic of persistent slip bands was for the first time found embedded in a matrix of veins in interior grains of polycrystals (fig. 1). This observation provides direct support for the physical picture of the Eshelby-Sachs model suggested for the fatigue limit of copper polycrystals. This model for the fatigue limit is being extended to account for the slope observed in the cyclic stress-strain curve for plastic strain amplitudes above the plateau. In a preliminary study the fatigue hardening of copper single crystals was semi-quantitatively explained by a composite model in terms of the observed dislocation microstructure. The result is consistent with the idea that hard

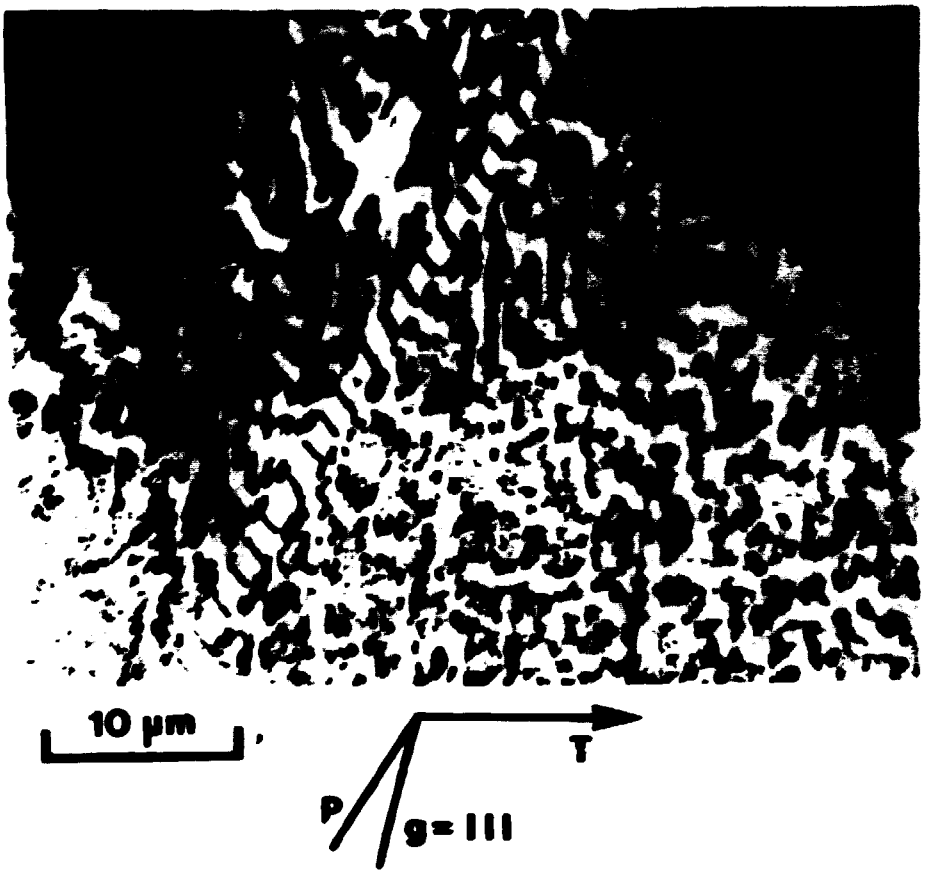

Fig. 1. A persistent slip band ladder in an interiour grain of a copper polycrystal fatigued in tension-compression. The amplitude of plastic strain was $\epsilon_p = 1.13 \times 10^{-4}$ and the wall spacing in the ladder structure is 1.4 µm, as observed in single crystals.

(elastic) veins play a role in the events leading to the nucleation of persistent slip bands.

Creep in fcc metals

A computer programme was written which simulates steady-state creep by dislocation movements in several slip systems, so that self-consistent values of the dislocation density and the dislocation link length distribution is obtained. Creep tests were made on specimens of pure Cu, and the resulting dislocation structures were examined by transmission electron microscopy.

Radiation damage in stainless steel
(in collaboration with the Metallurgy Division, AERE Harwell)

The investigation of the combined effects of silicon and helium on void nucleation and growth behaviour in a high purity austenitic stainless steel was extended to include the effects of higher silicon content and higher irradiation temperatures. Specimens containing 0.25-2.0 wt.% silicon and 10 atomic ppm of pre-injected helium were irradiated at temperatures up to 750°C in the Harwell high voltage electron microscope (HVEM). Beyond 600°C, the swelling rate in these specimens was found to increase rapidly with increasing irradiation temperatures. At higher irradiation temperatures, the nucleation of voids in the high silicon steels continues up to quite high doses, see fig. 2.

In order to determine the intrinsic effect of pre-injected helium on the growth rate of voids in the stainless steel with or without helium seeding experiments were carried out. In the seeding experiment a specimen without pre-injected helium was first irradiated (to a low dose) at a temperature lower than the final irradiation temperature. The specimen was then heated up to the final irradiation temperature and the same area was irradiated again. This treatment led to a higher void density which was comparable with that obtained in the specimen containing 10 atomic ppm of helium and irradiated at the same temperature. Thus, the effect of helium on the void growth could be separated from the effect of void density.

Study of defects in neutron irradiated copper by positron annihilation and TEM
(in collaboration with Chemistry Dept., Risø, and Metallurgy Division, AERE Harwell)

High purity copper (99.999%) specimens were irradiated in the DR 3 at 250°C to doses of 1×10^{22} n/m^2 and 5×10^{22} n/m^2. Angular correlation and positron lifetime measurements were made on specimens in the as-irradiated condition and after they were given post-irradiation isochronal annealing treatments at tem-

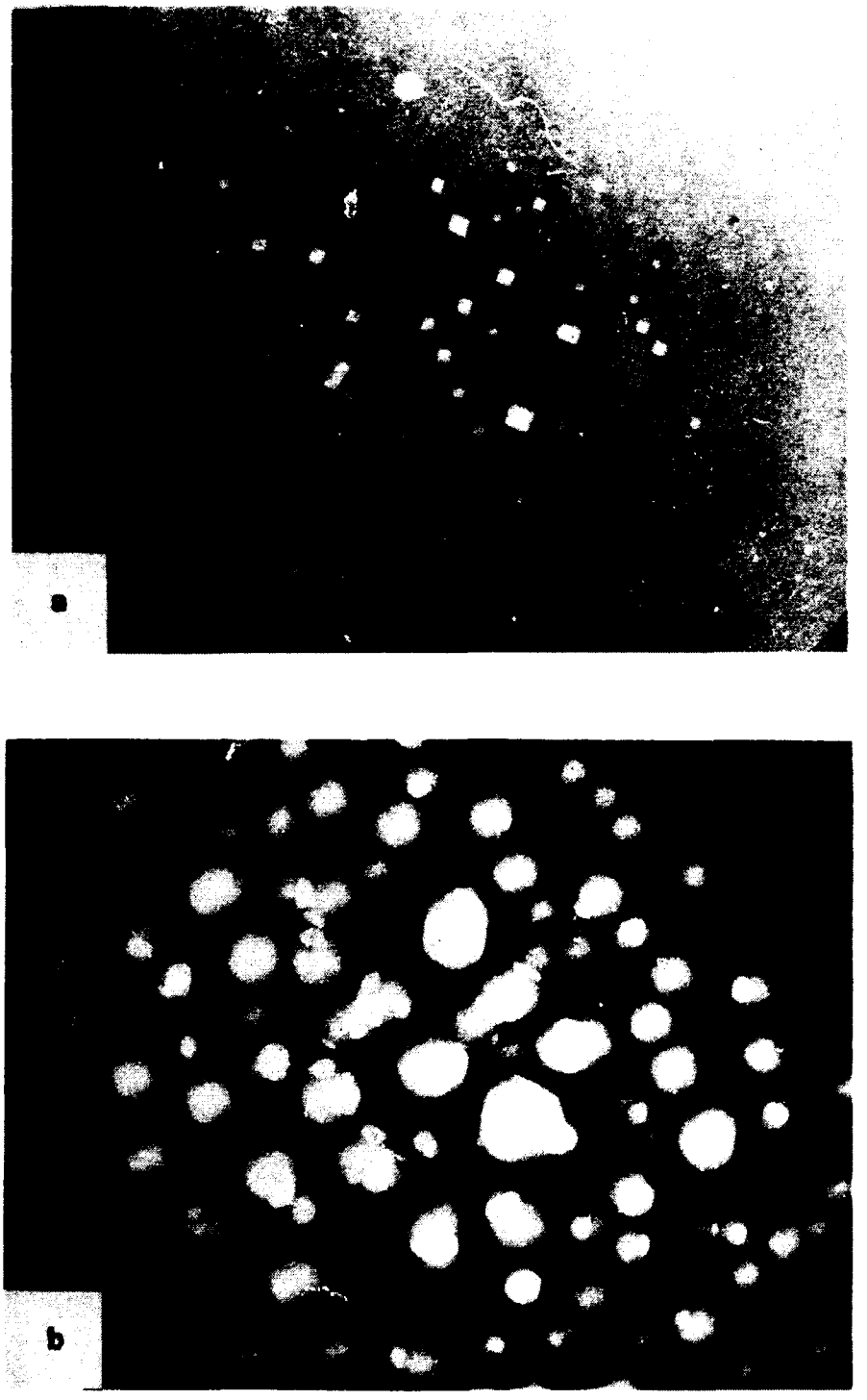

Fig. 2. Voids in an austenitic stainless steel containing 1.0 wt.% silicon and 10 ppm of helium. The specimen was irradiated with doses of 10.8 dpa (a) and 34 dpa (b) 1 MeV electrons at a temperature of 700°C.

peratures in the range 250 to 550°C. Corresponding specimens were examined by transmission electron microscopy (TEM).

The presence of voids gave rise to a long-life component (420±75 psec.) that disappeared during isochronal annealing at temperatures between 450°C and 550°C; this was in agreement with TEM observations. The effect of dislocation loops on the positron trapping was less clear.

On the basis of the positron trapping and TEM results it was proposed that the small (sub-microscopic) gas stabilized vacancy clusters (rather than dislocation loops) act as traps for positrons. It was also proposed that the trapping of positrons in deformed metals may take place at small vacancy clusters rather than at dislocations (as is usually assumed).

600 MeV proton irradiation

(in collaboration with EIR/SIN, Würenlingen, Switzerland)

Radiation damage results have been obtained on high purity aluminium with the use of a 600 MeV proton accelerator at the Swiss Institute for Nuclear Research (SIN) (fig. 3). The proton beam produces displacement damage (at a rate of 3.5×10^{-6} dpa s^{-1}), helium (60 atomic ppm per dpa), hydrogen (470 atomic ppm per dpa), and other impurities; helium, hydrogen and other impurities are produced through mutational reactions. The rates of displacement damage and the production of mutational impurities (including hydrogen and helium) during 600 MeV proton irradiation are similar to those expected in the first wall of a fusion reactor. With this proton beam we have irradiated thin sheets of aluminium (99.9999%) at 120°C to doses ranging from 0.2 to 2 dpa.

TEM discs were cut chemically from the centre of the irradiated samples. These discs were electropolished and the thin foils were examined in a 100 keV electron microscope.

The TEM results show that cavities form at all doses investigated. The cavity density is found to increase with increasing irradiation dose. At a given dose and irradiation temperature, the cavity density in the proton irradiated aluminium is higher than in similar aluminium irradiated with fast neutrons. At the dose level of 0.2 dpa, a relatively low density of large and well faceted cavities are observed. At the dose level of 2 dpa, on the other hand, two well defined and different populations of cavities are formed: one population consists of small, spherical cavities in a high density whereas the other population consists of large, clearly faceted cavities. The density of the large cavities does not seem to vary much with the dose whereas there is a considerable increase in the density of small cavities as the dose increases.

Fig. 3. Small cavities on a grain boundary and larger cavities at some distance from the boundary in proton irradiated aluminium.

Another significant aspect of our observations is that at the dose level of 2 dpa, a very high density of the small, spherical cavities are found to be present not only at the grain boundaries but also in the material immediately adjacent to the grain bound-

aries. The width of the zone immediately adjacent to the grain boundaries containing this high density of small cavities varies quite markedly from grain boundary to grain boundary.

The spatial distribution of both cavities and dislocations is very heterogeneous; very few dislocations are observed in the regions containing voids.

Void swelling in cold-worked stainless steel

The void swelling during irradiation in a high voltage electron microscope was studied in samples of solution-treated and of 10% cold-worked austenitic stainless steel at temperatures in the range 525-625°C. Preliminary results indicate that the void density is higher in the cold-worked than in the solution-treated material, whereas the swelling rate is about the same in the two materials. Similar experiments are done with Ni-ion irradiation at the KPTI, Kharkov, USSR, for comparison with the electron irradiation results.

Radiation damage in Ni-Sc and Cu-Ni alloys

Ni-Sc and Cu-Ni alloys were used as model materials for the study of alloying effects on void swelling. In the nickel-scandium system even a Sc content of 0.13% leads to a great reduction in void swelling; both Ni-ion and electron irradiation lead to the formation of special radiation-induced precipitates in Ni-Sc (work carried out in cooperation with the KPTI Kharkov, USSR). For copper-nickel the study of the growth rate of dislocation loops during high voltage electron microscope irradiation was continued as part of the investigation of the reduction in swelling produced by Ni additions in Cu.

The effect of low-dose neutron irradiation on copper

Pure copper was irradiated in the DR 3 reactor at Risø to doses of $1 \cdot 10^{22}$ and $5 \cdot 10^{22}$ neutron (fast)/m^2 at 250°C. The dose rate

was $3.5 \cdot 10^{17}$ neutrons (fast)/m^2/sec. The radiation-induced dislocations and voids were found to be very heterogeneously distributed. The dislocation loops and dislocation segments were situated in walls and blocks separated by almost dislocation-free zones of sizes in the range 2-10 μm. The voids were concentrated in the dislocation-free zones, the dislocation walls and blocks being almost without voids. The void swelling rate was found to be extraordinarily high: 5%/dpa for a dose of $5 \cdot 10^{22}$ n/m^2. It is very difficult to explain such a swelling rate in a material with the segregated structure described above. Rate-theory calculations (in cooperation with the KPTI, Kharkov, USSR) aiming at a theoretical description of the results are in progress.

Recrystallization of aluminium containing small alumina particles (in collaboration with the Danish Academy of Engineering)

The recrystallization behaviour of two-phase materials was studied in aluminium containing fine alumina particles (diameter < 0.1 μm). Cold-deformed specimens were heat-treated at temperatures below the recrystallization temperature in order to study the structural changes preceding nucleation. The dislocation mechanisms involved in subgrain growth were studied by transmission electron microscopy and by in-situ annealing in a high-voltage electron microscope.

The study of the recrystallization behaviour of commercial aluminium were continued with emphasis on the effect of grain size and degree of cold deformation on the nucleation processes.

Neutron diffraction investigation of recrystallization kinetics

Recrystallization is normally accompanied by changes in texture. By neutron-diffraction measurements these texture changes can be monitored in situ, which makes neutron-diffraction texture measurements a powerful potential tool for the study of recrystallization kinetics (fig. 4). A standard neutron spectrometer at the DR 3 reactor at Risø has been used in an investigation of the re-

crystallization kinetics of heavily rolled copper (work carried out in collaboration with the Physics Department). It was concluded that recrystallization took place by continued nucleation (throughout the recrystallization range) and subsequent fast growth of the new grains to the final size, which is not limited by other recrystallized grains, but by some, yet unknown, inherent growth limiting factor. The investigation demonstrated the great potential of in-situ neutron diffraction texture measurements. Various technical improvements, such as faster registration of texture data, are now being implemented.

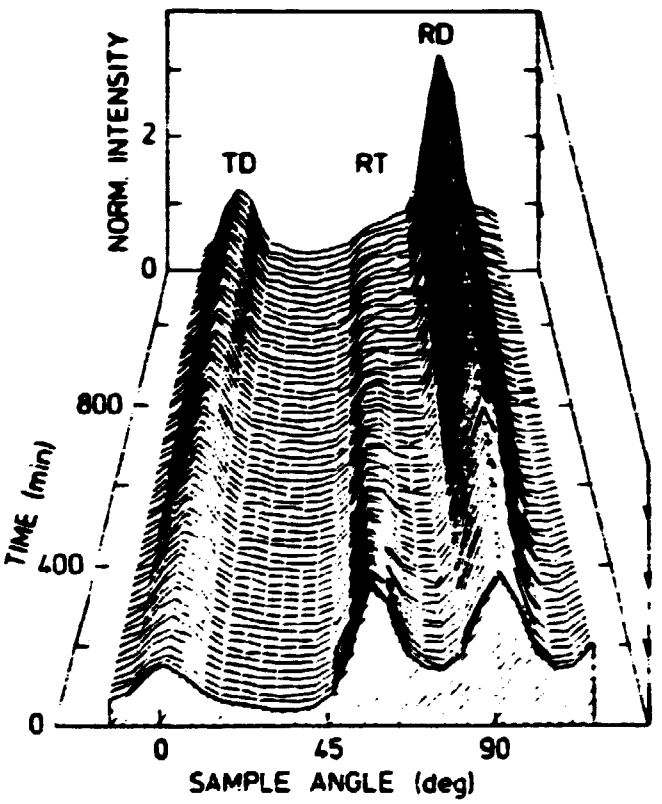

Fig. 4. Recrystallization in copper at 248°C followed by neutron diffraction texture measurement. The figure shows the change with time of the intensities along the great circle in the pole figure connecting the rolling direction and the transverse direction.

The reaction of hydrogen with Fe-Ti alloys

Work was continued on the hydrogen uptake by the α-phase in the iron-titanium-hydrogen system. The reaction rate of the absorption process was measured and the equilibrium isotherm was determined using microbalance and volumetric techniques.

Diffusion rather than surface reactions was found to be rate controlling at higher temperatures (300-500 K). At lower temperatures (80-90 K) absorption did not take place, and adsorption of hydrogen could be detected. The surface reaction was found to have a very small activation energy, if any, and to be dissociative.

Neutron scattering studies of solid electrolytes

The neutron scattering studies on the solid electrolyte $LiI \cdot D_2O$ (H_2O) were continued with the purpose of examining the role of the D_2O-molecule in the Li-conducting process. $LiI \cdot D_2O$ (H_2O) has an ionic conducting phase (β-phase) below the melting point at 120°C ($\sigma = 4 \times 10^{-3}\ \Omega^{-1}\ cm^{-1}$). The β-phase is cubic (space group Pm3m) with a built-in surplus of equivalent positions for the conducting Li-ions. The orientation of the water molecules at the body centre are disordered with the preferred hydrogen sites lying along the body diagonals. A first-order structural transition to an orthorhombic phase (α-phase) was observed at -66°C. Studies of the relations between the diffuse scattering observed in the β-phase and the structure of the α-phases in $LiI \cdot D_2O$ and the other Li-halide-monohydrates were initiated. Inelastic neutron scattering studies of the phonon spectrum in the β-phase were performed. The acoustic branches appear without anomalies; the optical branches could not be resolved.

The collaboration with Chalmers University of Technology on the structural studies of the ionic conducting high temperature cubic phases of $LiXSO_4$ (X = Li,Na,Ag) was extended. In combination with the results of X-ray diffraction experiments, refinement analysis was initiated with the purpose of investigating the lattice posi-

tions of the moving ions. In order to study the structural properties of Li_2SO_4 by quasielastic neutron scattering, a method of growing single crystals in the high temperature conducting phase was developed.

Studies on nonstoichiometric wüstite ($Fe_{1-y}O$) and cobaltowüstite ($(Co,Fe)_{1-y}O$)

The thermodynamic properties and the defect structure of $Fe_{1-y}O$ and $(Co,Fe)_{1-y}O$ were studied by thermogravimetric measurements in flowing CO_2/CO and N_2/air atmospheres with various oxygen pressures, which were measured with a $ZrO_2(CaO)$ solid electrolyte oxygen concentration cell. The measurements were performed at three temperatures (900, 1050 and 1200°C) on samples with the compositions N_{CO} = 0, 0.808 and 0.941 respectively. The partial molar thermodynamic quantities for oxygen, ΔG_{O_2}, ΔH_{O_2} and ΔS_{O_2} were calculated from the known oxygen pressures and plotted as functions of the composition (log y) determined in the thermogravimetric measurements. In this way the type of defects present in the nonstoichiometric phases was evaluated. This analysis showed that the nonstoichiometric phase regions in all cases can be divided into subregions each with a characteristic defect structure. For small deviations from the stoichiometric composition the data indicates that a basic complex ($4V_M''-Fe_i^{\bullet\bullet}$) is formed at high temperature whereas this at lower temperatures associates into a much larger complex consisting of $16V_M''-5Fe_i^{\bullet\bullet}$. At larger deviations from stoichiometry, however, the data indicates a high degree of ordering especially in the $(Co,Fe)_{1-y}O$-system.

Thermogravimetric studies of decomposition of ammonium-uranyl carbonate (AUC) under simulated industrial conditions

A series of measurements was carried out in a modified thermobalance system in which the rapid heating of the AUC powders, characteristic of the industrial process, could be simulated.

The measurements were performed in H_2/H_2O atmospheres, with compositions actually used industrially. From the data obtained the kinetics of the different steps involved in the decomposition and subsequent reduction of AUC could be evaluated. For the first step in the process, AUC → $UO_3(H_2O)_x$, and second step, $UO_3(H_2O)_x$ → UO_3, the data showed that the decompositions are controlled by a spherically symmetric diffusion process with the activation energies E_I = 79.5±6.9 kJ/mole and E_{II} = 48.5±4.9 kJ/mole respectively.

TECHNOLOGY AND MATERIALS DEVELOPMENT

Materials testing

A servohydraulic testing machine (Instron 1332, ±100 kN) was installed and used for precracking fracture mechanical tests. A fixture was constructed for gripping glass-fibre reinforced plastics in fatigue tests and the computerized data sampling system for static tests was further developed. Other major activities were: static tests of fibre composites, plane stress-strain deformation of copper single crystals, tensile tests of copper polycrystals at room temperature and at low temperature (77K), fatigue tests of copper polycrystals and fibre composites, and measurements of the residual lifetime of high temperature components.

Elasto-plastic fracture mechanics

A single specimen test procedure for the determination of the notch toughness J_{IC} and the tear modulus T, based on the establishment of a resistance curve, was investigated (fig. 5). The procedure involves the testing of a compact tension specimen and the DC potential difference technique is used to provide a continuous measurement of the ductile crack growth during the test. The correlation between the potential difference and the crack growth is based on a reference curve.

Irradiation embrittlement of reactor pressure vessel steels

Investigations of the fracture toughness of irradiated reactor pressure vessel steels of various origins were initiated as part of a collaborative IAEA programme. Fatigue-precracked and 15% side-grooved specimens of a CVN-like geometry were irradiated to a maximum dose of 5×10^{20} n/cm^2 at 290°C and tested in slow

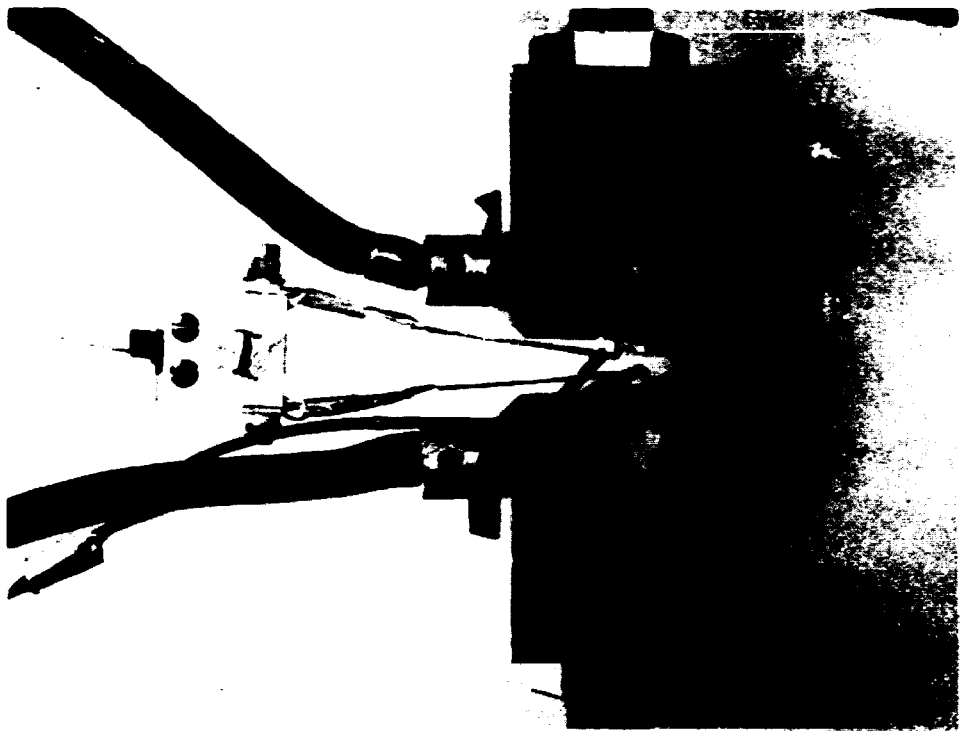

Fig. 5. A compact tension specimen with a clip gauge, current-leads and potential wires to provide continuous readings of the ductile crack growth.

bending corresponding to the multispecimen J-resistance curve procedure. Unirradiated specimens were tested and the resistance curve obtained was found to agree qualitatively with results from the literature.

Brazing and soldering

Investigations of the brazing of metals to ceramics were continued with studies of the wettability during high temperature vacuum brazing of Fe-Ni-Cr alloys to high-purity Al_2O_3. It was found that the Ti cored Ag-Cu eutectic filler metal always wets the Al_2O_3 surface while it does not always wet the metal surface.

The contract work on industrial applications of dip-brazing, vacuum brazing and ultrasonic soldering of aluminium as well as vacuum brazing of stainless steels and nickel alloys was continued.

Fibre-reinforced plastics

Research and development on fibre reinforced plastics were continued in the following fields: fabrication technology, testing methods, mechanical properties and design and analysis.

Within fabrication technology the filament winding machine was completed, and various shapes of near-cylindrical mandrels were investigated. Techniques were examined for extracting the mandrel from the wound tubes. A microprocessor is being installed for numerical control of the winding process. The autoclave for curing of laminates was completed and used for fabrication of laminates of size 350 x 700 mm^2; the pressure and temperature cycles can be controlled numerically. Several glass fibre/polyester materials of special configurations were fabricated by hand-lay-up and room temperature curing.

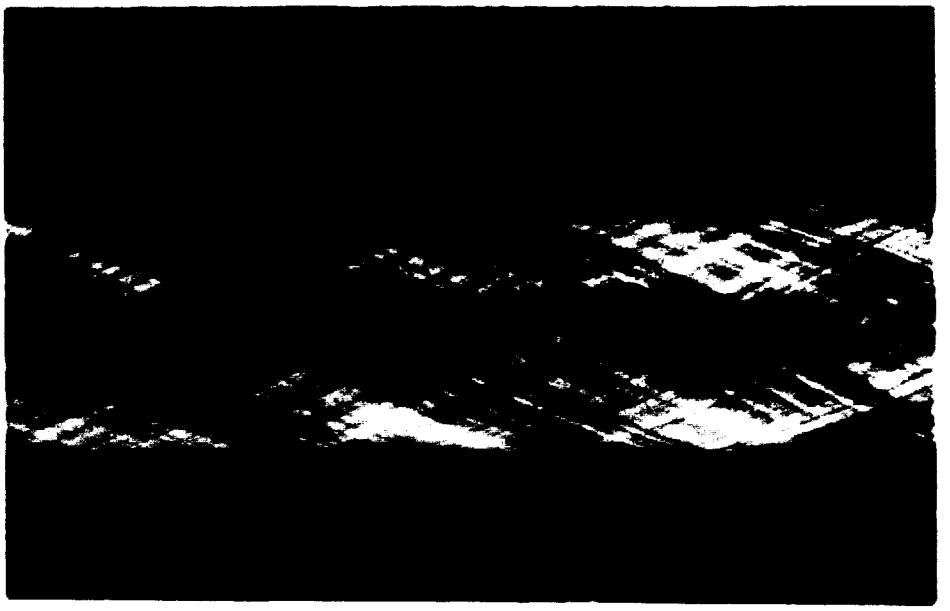

Fig. 6. Filament wound tube of glass/polyester.

Within testing of composite materials investigations were made of requirements to the size, shape, aspect ratio and gripping of specimens for tensile testing under static and dynamic loading. In particular, the anisotropy of the materials was considered.

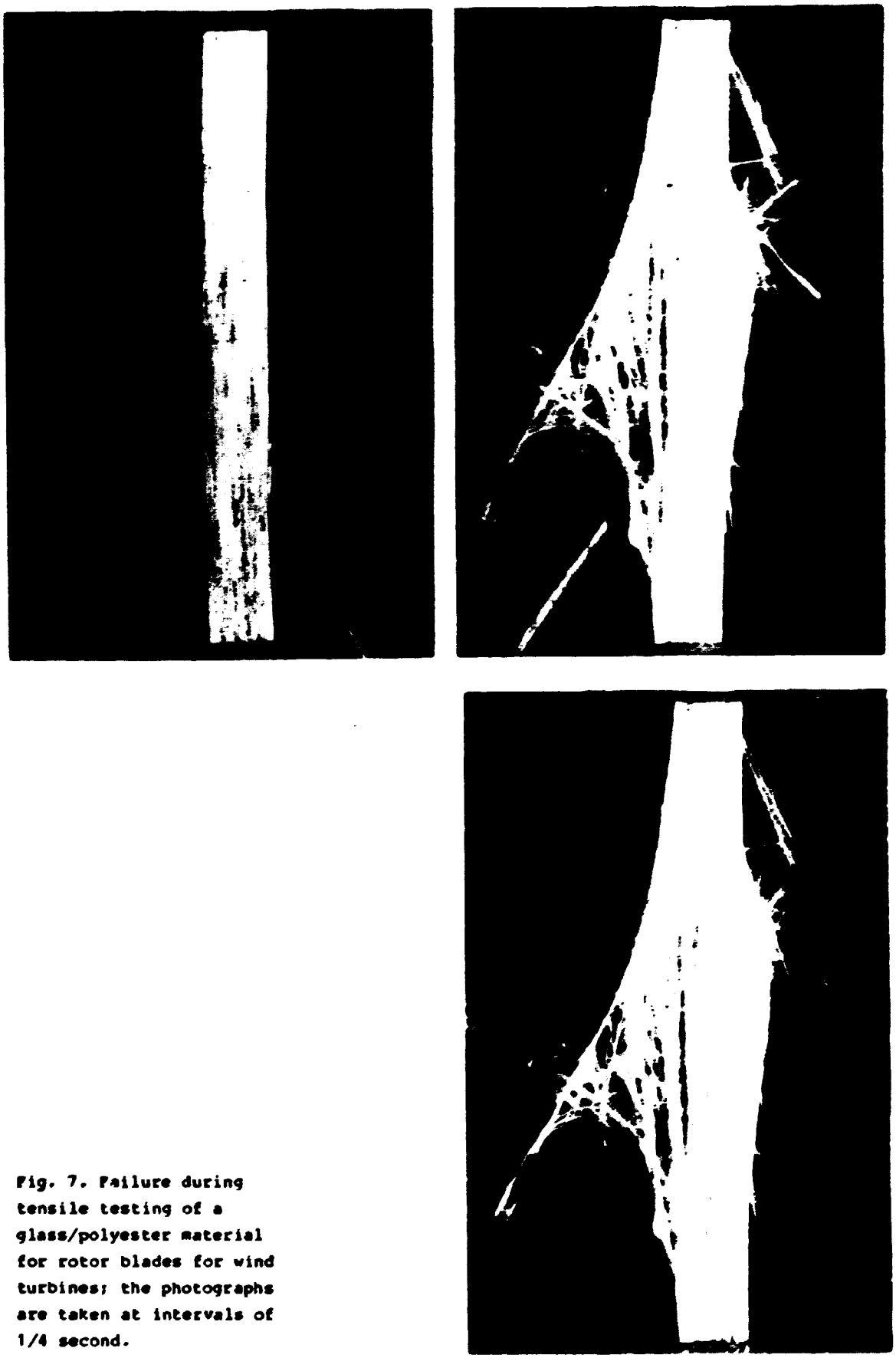

Fig. 7. Failure during tensile testing of a glass/polyester material for rotor blades for wind turbines; the photographs are taken at intervals of 1/4 second.

Within mechanical properties studies were made of the fatigue behaviour of glass fibre/polyester. Materials with unidirectional fibres were characterized by the change of the elastic constants during fatigue. Materials with cross-plied fibres were tested in fatigue to establish data for design purposes. Fatigue data for glass fibre/polyester materials were collected from the literature, with special reference to data for very large numbers of cycles.

Several projects for the industry were carried out in the fields of fabrication technology, materials testing and design and analysis, related to both glass fibre/polyester and carbon fibre/epoxy materials.

Projects sponsored by the government include fatigue properties of the glass fibre/polyester material used for the rotor blades for two large wind turbines and work on a guide for design and properties of fibre composite materials.

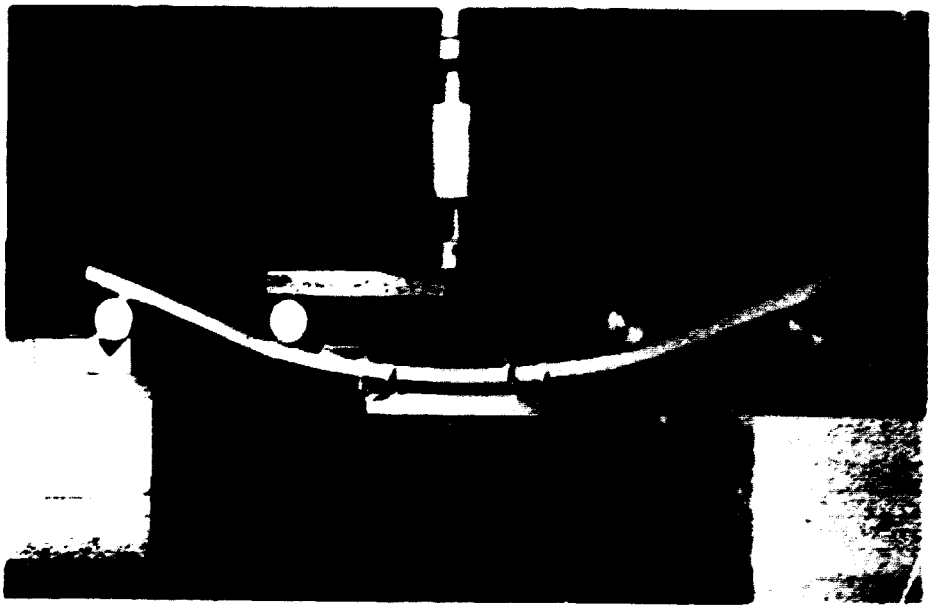

Fig. 8. A sandwich laminate with a core of PVC foam and skins of glass/polyester is tested in bending.

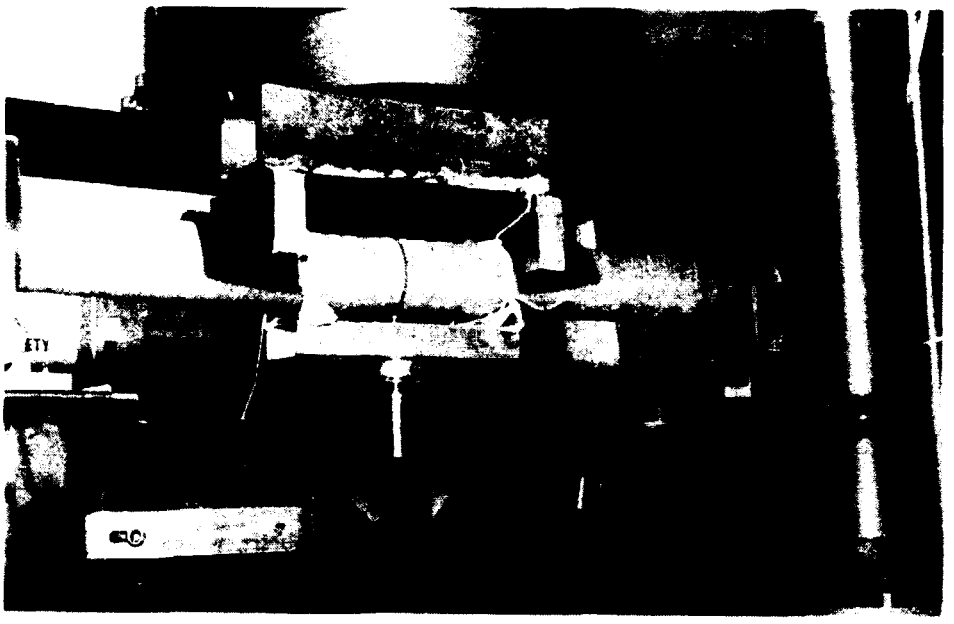

Fig. 9. An experimental tube of tape-wound glass/polyester is tested in bending.

Machining of carbon-fibre-reinforced plastics

Carbon fibres are hard and abrasive. Therefore most tool materials - including cemented carbides - are worn out quickly when used for machining of composites containing carbon fibres. The cutting process consists of a series of fractures, by each of which a small chip is removed. The cutting process thus depends on the orientation of the fibres with respect to the cutting edge. A series of experiments was made with cutting parallel to the fibres of a unidirectional composite in order to study the effect of the cutting force. Experiments on drilling were also made.

Metal-hydrogen systems

Comminuted magnesium reacts readily with hydrogen above 250°C at hydrogen pressures at or slightly above the corresponding equilibrium pressure for magnesium hydride. The reaction rate depends

Fig. 10. Microbalance facility for studying reactions in metal-hydrogen systems. The balance unit (top centre) operates with a sensitivity of 1 µg at pressures up to 150 bar and temperatures up to 650°C.

upon the specific surface area. Powders with particle diameters below approximately 100 µm gave a fast reaction with formation of stoichiometric MgH_2, for instance at 400°C and 3.5 MPa the reaction was completed in less than 10 minutes for powders with particles below 50 µm. Powders with large particles gave slow rates and incomplete reaction. The desorption of hydrogen shows similar trends, but the reaction rate at a given temperature is slower than for sorption.

In order to evaluate the feasibility of using magnesium as a hydrogen storage medium, the influence on the sorption properties of surface conditions, metal purity and exposure to air was investigated together with the morphological stability during cycling between the metal and the hydride phases. The investigation indicated that magnesium may be a useful storage medium for

Fig. 11. Scanning electron micrograph showing the surface of a mechanically manufactured magnesium particle.

hydrogen, and the studies are therefore continued with the aim of presenting a complete list of properties necessary to guarantee acceptable hydrogen reaction and a set of handling procedures.

Solid electrolytes for lithium batteries

The development and characterisation of ionically conducting solids for potential use as electrolytes in rechargeable lithium batteries were continued. Composite electrolytes (LiI-Al_2O_3) are being optimised with respect to conductivity and electrochemical stability (part of an Anglo-Danish EEC sponsored programme). An automated method of determining AC conductivities as functions of temperature is being developed. The following electrolytes were studied: LiI, LiI·H_2O, LiI·D_2O, LiI-Al_2O_3, Li_2CO_3, $LiBiO_2$ and potassiumbetaalumina. They all show high conductivities at elevated temperatures; but their conductivity is not high enough at the operation temperature (< 200°C) of the future batteries.

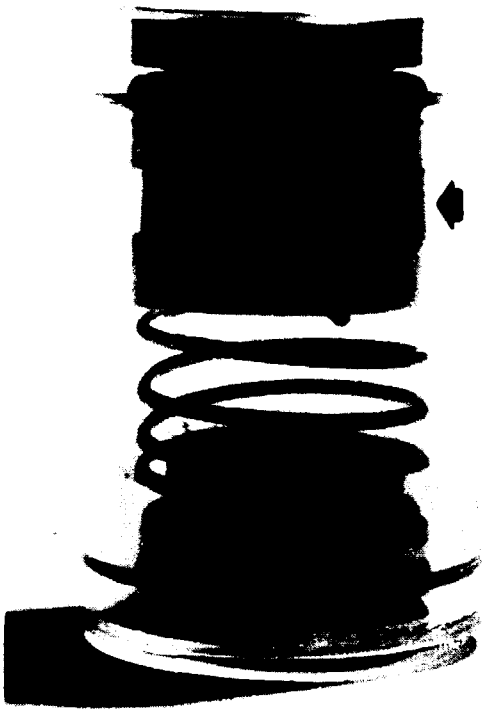

Fig. 12. All solid state battery in a test container. The battery consists of a Li-cell with a LiI based solid electrolyte.

Oxygen conducting solid electrolytes

The quasi-isothermal dilatometric method was used in a sintering study of CeO_2-Gd_2O_3 powder compacts. Contrary to conventional sintering techniques the optimum heating rate can be determined in a single run by this technique, in which the heating is automatically stopped when the sintering rate becomes higher than a preset limit. From the shrinkage curve the controlling mechanism and its activation energy can be determined. From the data obtained on the CeO_2-Gd_2O_3 compacts it was shown that the sintering takes place in six steps with activation energies in the range of 50-210 kJ/mole. More measurements are needed to establish the mechanisms controlling these steps.

In-pile corrosion testing of Zr-alloys

The corrosion testing of SCANUK alloys (experimental Nb-containing Zr-alloys, developed during the Anglo-Scandinavian cooperation on zirconium alloys) was finished with in-pile corrosion testing in DR3 under simulated BWR conditions. Zircaloy-2 was used as a reference material. The SCANUK alloys showed specific weight gains a few times higher than that of Zircaloy-2 after an exposure time of 134 days. Of special interest was the result that the oxygen concentration within the range from about 0.1 ppm to 3 ppm had only a negligible influence on the in-pile corrosion behaviour of all the alloys, including Zircaloy-2.

High temperature materials

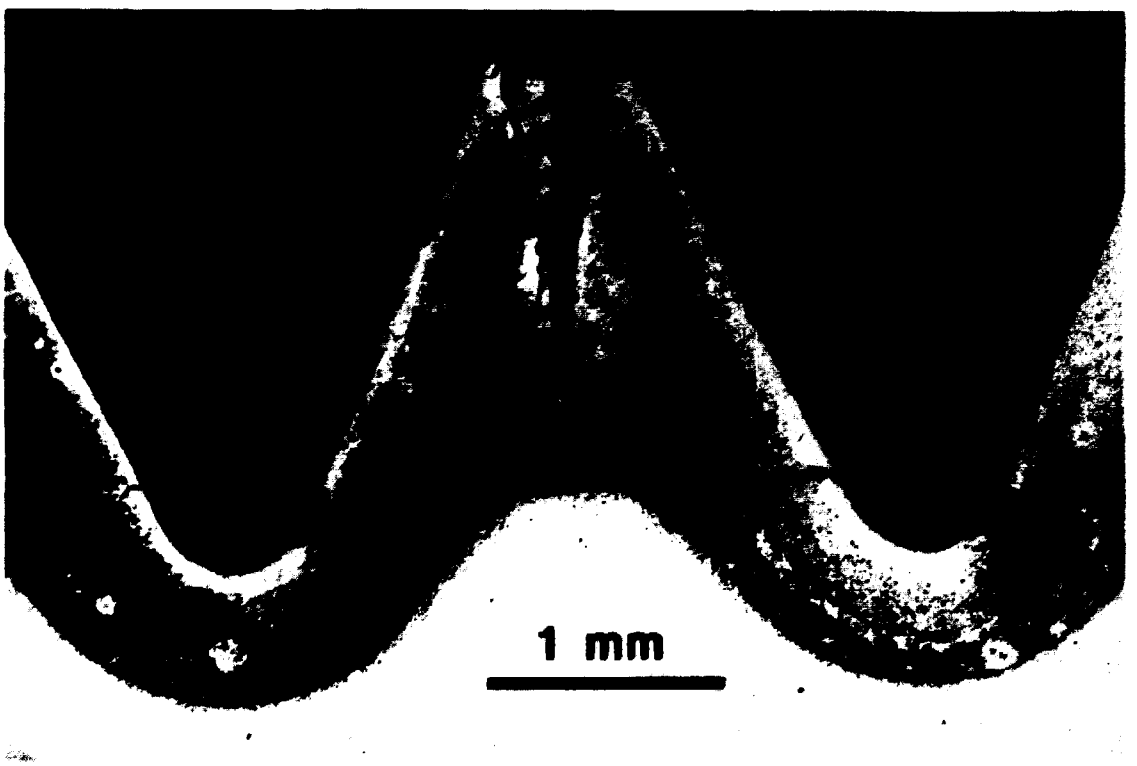

Fig. 13. Thread of bolt (martensitic stainless steel, 12% Cr) damaged by nitriding in an ammonia containing atmosphere (16% NH_3, 480°C, five years).

The behaviour of materials in certain high-temperature components in the chemical industry was studied, partly in connection with contract work. The investigations concentrated on the behaviour of centrifugally cast 25/20 stainless steel tubes for catalytic steam reformers and on components from ammonia converters. In particular, the nitriding of 18/8 stainless steel and of alloy 600 in ammonia environments was studied.

Erosion-corrosion of steel

The construction of a special apparatus for investigation of erosion-corrosion by slurry flow in tubes at temperatures up to 300°C was completed. With this apparatus the erosion-corrosion properties of unalloyed carbon steel and a low-alloy steel in fluoride- and chloride-containing bicarbonate solutions will be investigated with a view to selection of materials for the uranium pilot plant.

Investigations in stagnant solutions indicate that the agressiveness of concentrated bicarbonate solutions is not increased by substantial additions of fluoride and minor additions of chloride.

NON-DESTRUCTIVE TESTING

The projects in this field deal with the development and application of non-destructive techniques for various testing purposes.

Neutron radiography

Standardization work in the field of neutron radiography was implemented within the Neutron Radiography Working Group, which was formed in 1979 under the auspices of Euratom. This group prepared a programme, which covers characterization of facilities, exposure and development of films and apparatus and methods for dimensional measurements directly on the films. In this first programme the work was specified for the examination of nuclear fuel elements.

Every participating facility will obtain a standard set of tools which are prepared by Risø National Laboratory, namely a fuel pin with well-defined gaps both diametral and longitudinal, a beam purity indicator, a sensitivity indicator and the necessary film material.

Ultrasonic inspection

A PDP 11 minicomputer was programmed and interfaced to the system built for three-dimensional rotational scanning of sound waves from ultrasonic transducers. This enables the system to measure and record an accurate and detailed picture of the sound field within a few minutes. The raw data are stored on a floppy disc and subsequent calculations and data plots can be made at any desired time. Modifications are being made to enable the system to inspect more traditional transducers in addition to the ultrasonic transducers. With minor modifications the system can

also be used for non-destructive measurements of dimensions and materials properties.

Post-irradiation examination

Nuclear fuel experiments have in recent years concentrated on the release of fission gas during power transients. A non-destructive method for assessment of the release of fission gas to the plenum of a fuel pin was developed. The method is based on gamma spectrometry and can be carried out immediately after removal of a fuel pin from the reactor core. As the measurement takes place without affecting the integrity of the object, it is possible to make multiple tests on the same fuel pin at different irradiation levels.

Quantitative image analysis

A semiautomatic image analysis system was installed with the purpose of improving the quantitative image interpretation. The system comprises a digitizer tablet, which is connected to a microprocessor with two integrated floppy disc drives, a video memory, data screen and a printer/plotter. Geometrical data can be obtained by outlining the structure.

FUEL ELEMENTS

The Danish fuel elements in the Kahl and Halden reactors continue to perform well and to demonstrate the adequacy of the design and manufacturing processes.

The irradiation of UO_2-Zr fuel pins in the DR 3 reactor at Risø includes standard BWR and PWR type tests irradiated to very high burn-ups. Special tests such as "bump tests" are also being made within the Risø Fission Gas Project.

Additional information on fuel performance becomes available as a result of international collaboration arrangements, i.e., the OECD Halden Reactor Project (Norway), the "Demo-Ramp II" (BWR fuel) and the "Super-Ramp" (PWR and BWR fuel) projects at Studsvik (Sweden), Battelle's "High Burnup Effects Program", the information exchange with the NRC (USA), and the EEC sponsored activities (Brussels) relating to Pu recycling in LWRs.

An IAEA Specialists' Meeting on "Pellet-Cladding Interaction in Water Reactors" was held at Risø 22-26 September 1980. The proceedings of the meeting will be published by the IAEA.

Danish fuel element irradiations in the Kahl and Halden reactors

The four Danish fuel elements in the German BWR power reactor went on power for the first time in 1975. Irradiation was continued and these elements have now achieved an estimated average burn-up of 16,500 MDW/t UO_2. Two short tests fuel pins, manufactured from the same UO_2 and Zr materials as the Kahl fuel pins, have now reached a burn-up of 39,200 MWD/t UO_2 in the DR 3 reactor.

Irradiation of the four test fuel elements in the Halden reactor (Norway) was continued. They have now reached the following esti-

mated burn-ups (average assembly, after correction for fuel depletion):

IFA No.	161	165	201	202
MWD/t UO_2	35,200	33,100	30,500	26,700

The maximum local burn-up of 42,000 MWD/t UO_2 was achieved with IFA 161.

UO_2-Zr irradiations at Risø

In the test fuel irradiation programme at the DR 3 reactor, standard fuel pins have reached max. burn-up levels of 55,700 and 48,400 MWD/t UO_2 for BWR and PWR type fuel, respectively.

Further post-irradiation examination and evaluation was carried out on ramp-tested vipac and pellet fuel from a Danish Halden assembly (IFA 164). Four Zircaloy-clad vipac pins and one pellet pin failed in fast ramps at peak heat loads of 411-459 W/cm and the pellet pin failed at 348 W/cm. The fourth vipac pin was conditioned at 379 W/cm for 2 days; with a slow ramp rate of 5 W/cm·min, an overpower level of 528 W/cm was reached without failure indication. An evaluation of the local overpower levels and the eddy-current observations showed that the vipac pins had an advantage of about 80 W/cm over the pellet pin in terms of minimum heat load required for interaction and defection. The many cladding cracks seen in one of the failed vipac pins had the usual brittle appearance attributed to stress-corrosion cracking.

The Risø fission gas project

The objective of this project is to provide well-characterized experimental data on fission gas release and other aspects of the high-burnup performance of water reactor fuel. The project is sponsored internationally by fuel suppliers, electric utilities and nuclear safety and research organizations.

Fig. 14. Stress-corrosion type cracks in the Zircaloy cladding of a vipac UO_2 fuel pin that failed in ramp testing.

UO_2-Zr fuel pins were previously irradiated to peak pellet burn-ups exceeding 35,000 MWD/t UO_2. Most of these fuel pins are subjected to a short re-irradiation ("bump test") in the DR 3 reactor at Risø, in order to simulate postulated power increases late in life for power reactor fuel. A gamma spectrometry technique developed at Risø permits a non-destructive assessment of the fission gas content of a fuel pin, thus enabling repeated bump testing prior to the ultimate destructive examinations. These include fission gas measurements, fuel characterizations etc. The project period is 1980-81.

Evaluation of LOWI fuel performance

In collaboration with UKAEA, BNFL and Elsinore Shipyard the performance of the special low-interaction UO_2 pellet design LOWI was evaluated using reactor physics codes and fuel performance codes. It was found that the use of LOWI fuel will increase the

total fuel cycle cost by 2-5% depending on the choice of parameters. Ramp performance calculations indicate that relaxed operating restrictions can lead to a gain of 25 to 75 full load hours per year of operation.

PARTICIPATION IN INTERNATIONAL COLLABORATION

The department is engaged in the following types of international collaboration: joint technical projects, committee work, reception of research fellows, and technical and scientific meetings. The cooperation programme on irradiation damage between the department and the Kharkov Physical-Technical Institute was continued.

The department was represented on the following committees:

The Information Exchange Group under the European Space Agency on Carbon Fibre Reinforced Plastics,

The Halden Programme Group,

The IAEA International Working Groups on "Reliability of Reactor Pressure Components" and "Water Reactor Fuel Performance and Technology",

The Over-Ramp, Super-Ramp and Demo-Ramp Project Committees,
The Project Committee on the Battelle HBEP-Programme.
The OECD/EEC Nuclear Agency's Committee on the Safety of Nuclear Installations (NEA-CSNI) Working Group on Safety Aspects of Steel Components in Nuclear Installations,

The COST 501 Committee on Materials for Energy Conversion using Fossile Fuels,

The EEC Advisory Committees for Programme Management: "Plutonium and Transuranium Elements", "High Temperature Materials" and "Plutonium Recycling in Thermal Reactors",

The European Coal and Steel Community,
Executive Committee No. 5: Failure Mechanisms and Design,

The Council of the International Confederation of Thermal Analysis,

The Nordic Committee for Thermal Analysis,

and in the Technical Commission of the International Institute of Welding, Commission I, "Gas Welding and Allied Processes", Subcommission A, "Brazing and Surfacing".

EDUCATION AND TRAINING

N. Hansen and K. Rørbo gave regular lectures on materials science to students at the Danish Academy of Engineering. N. Hansen, T. Leffers and H. Lilholt acted as external examiners at examinations for the Technical University of Denmark, and O. Toft Sørensen acted as external lecturer at the Technical University of Norway, Trondheim.

One scholarship holder from Egypt worked in the Department on projects in the field of non-destructive testing.

Post-graduate projects

Three post-graduate students from the Technical University of Denmark and one from the University of Copenhagen worked in the Department on the following projects in preparation for their licentiate (Ph.D.) theses:

A. Schrøder Pedersen:	Kinetics of the hydrogen uptake in and release from Fe-Ti alloys
A. Koplev:	Machining of fibre-reinforced plastics
J. Vestergaard Sørensen:	Thermomechanical forming processes
D. Justesen:	Investigation of recrystallization kinetics by neutron diffraction texture measurements.

PUBLICATIONS

Ny brændselstype til atomkraftværker (A New Type of Fuel for Nuclear Power Plants).

J. Aukdal, H. Frederiksen and A. Jensen, Jernkont. Ann. 164 No. 1 (1980) 49-51.

The article describes technical and economical aspects of the low-interaction UO_2 pellet design LOWI.

Calculation of Heat Rating and Burn-Up for Test Fuel Pins Irradiated in DR 3.

C. Bagger, H. Carlsen and K. Hansen, Risø-M-2185 (1980) 50 pp.

A summary of the DR 3 reactor and HP1 rig design is given followed by a detailed description of the calculation procedure for obtaining linear heat rating and burn-up values of fuel pins irradiated in HP1 rigs. The calculations are carried out rather detailed, especially regarding features like end pellet contribution to power as a function of burn-up, gamma heat contributions, and evaluation of local values of heat rating and burn-up. Included in the report is also a description of the fast flux- and cladding temperature calculation techniques currently used. A good agreement between measured and calculated burn-up values is found. This gives confidence to the detailed treatment of the data.

The Deformed Structure of Grain Boundaries in Aluminium of Commercial Purity and in an Aluminium-Alumina Alloy.

B. Bay and N. Hansen, In: Recrystallization and Grain Growth of Multi-Phase and Particle Containing Materials. Proceedings of the 1st Risø International Symposium on Metallurgy and Materials Science, Risø, 8-12 September 1980. Edited by N. Hansen, A.R. Jones and T. Leffers (Risø National Laboratory, Roskilde, 1980) 51-56.

The deformed structure at grain boundaries of commercial aluminium with a purity of 99.4% and of an aluminium-0.7 wt.% alumina alloy with a comparable purity of the aluminium matrix was studied by transmission electron microscopy. The materials were deformed 50% by cold-rolling. At the majority of the grain boundaries the misorientations were small, but at some of the boundaries bands containing cumulative misorientations with a large orientation spread were observed. Sometimes this type of orientation spread was

strongly increased in the vicinity of $FeAl_3$ particles. A small fraction of the $FeAl_3$ particles which were situated at grain boundaries otherwise showing only small local misorientations, produced large lattice rotations close to the boundary, sometimes forming a complex structure as above. The types of deformed structures at grain boundaries are discussed with reference to their ability to form recrystallization nuclei.

The Nucleation of Recrystallization in a Powder-Produced Nickel-Base Superalloy. In: Recrystallization and Grain Growth of Multi-Phase and Particle Containing Materials.

J.V. Bee, A.R. Jones, and P.R. Howell, Proceedings of the 1st Risø International Symposium on Metallurgy and Materials Science, Risø, 8-12 September 1980. Edited by N. Hansen, A.R. Jones, and T. Leffers. (Risø National Laboratory, Roskilde, 1980) 153-158.

The nucleation of recrystallisation in powder-produced carbon astroloy has been found to occur adjacent to grain boundaries, associated with coarse γ' precipitates. The formation of viable recrystallisation nuclei is achieved by a sub-grain coalescence mechanism. Carbide particles do not appear to act as potential nucleation sites. The initial recrystallised grains contain a γ' precipitate dispersion markedly different from that observed in later stages of the recrystallisation process. This has been explained in terms of growth of these grains in a γ'-depleted matrix, leading to the homogenous nucleation of spherical γ' precipitates in the recrystallised grains.

Fission Gas Release in LWR Fuel Rods Exhibiting Very High Burn-Up.

H. Carlsen, Nucl. Eng. Design 56 (1980) 183-187.

Two UO_2-Zr BWR type test fuel rods were irradiated to a burn-up of about 38000 MWd/t UO_2. After non-destructive characterization, the fission gas released to the internal free volume was extracted and analysed. The irradiation was simulated by means of the Danish fuel performance code WAFER-2, which uses an empirical gas release model combined with a strongly burn-up dependent correction term, developed by the US Nuclear Regulatory Commission. The paper presents the experimental results and the code calculations. It is concluded that the model predictions are in reasonable agreement (within 15%) with the experimental results. No similar agreement could be obtained without the burn-up dependency of the release model.

Brudkontrol gennem materialekendskab (Control of Fracture through Knowledge of Materials Properties).

C.P. Debel, In: Revner og Brud (Cracks and Fracture). Dansk Metallurgisk Selskabs Vintermøde, Hindsgavl, 9-11 januar 1980. Edited by E.W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1980) 61-83.

A variety of testing methods used to measure notch toughness of materials are surveilled. The methods are divided into a qualitative and a quantitative group with respect to their usefulness in a fracture mechanics context. The fracture criteria behind the methods are mentioned.

Nye radiografiske produkter: radiografisk papir og nitrocellulosefilm. (New Radiographic Products: Radiographic Paper and Nitrocellulose Film).

J.C. Domanus, Svejsning 7, No. 2 (1980) 12-13.

Effort has been made to improve the quality of the radiographic image and decrease the cost of the radiographic control, which has resulted in the introduction on the market of two new products: radiographic paper for X-ray radiography and nitrocellulose film for neutron radiography. Both products can be used instead of X-ray film and both require a special processing. The main advantage of the use of the radiographic paper is its relative high speed and low cost, whereas nitrocellulose film gives neutron radiographs of higher quality.

Nye radiografimetoder taget i brug til ikke-destruktiv kontrol af reaktorbrændsel. (New Radiographic Methods applied in Non-Destructive Control of Nuclear Fuel).

J.C. Domanus, Dansk Tekn. Tidsskr. 104, No. 9 (1980) 12-15.

X-ray radiography is used for the quality control during the fabrication of nuclear fuel elements for the Danish DR 3 reactor, whereas neutron radiography is used in the post-irradiation examination of nuclear fuel. New products and methods used for both purposes are described. In the field of neutron radiography standardization is necessary and therefore Denmark has initiated that kind of work within Euratom. Highlights of activities of an Euratom working group (of which the author is a chairman) are given.

Radiographic Control of Mineral Fibre-Reinforced Cement Plates.
J.C. Domanus and L. Møller Jensen, In: Advances in Composite Materials, Proceedings of the 3rd International Conference on Composite Materials, Paris, 26-29 August 1980. Edited by A.R. Bunsell, C. Bathias, A. Martrenchar, D. Menkes and G. Verchery (Pergamon Press, Oxford, 1980) 959-972.

The usefulness of the radiographic technique in the examination of Spinrock fibres reinforced cement plates was investigated with soft X-rays. A preliminary investigation has shown that soft X-rays are most suitable for radiography of cement plates, and therefore a 50 kV X-ray machine with a 0.5 mm focus and beryllium window X-ray tube was used throughout the investigation. X-ray films of different speed and graininess were used, and it was proved that a relatively fast Kodak Industrex D film can produce radiographs of adequate quality. An Agfa-Gevaert Structurix IC paper can also be used.

Radiographs of cement plates, taken both on X-ray film and paper were scanned using a transmission or reflection densitometer. Optical density readings from the densitometer were fed into a paper chart recorder.

The results of the radiographic test were transferred to a quantitative measure by densitometer scanning from which the relative standard deviations in the optical densities were used. These measures show a significant correlation with the flexural strengths, measured on the same specimens.

We therefore conclude that the material distribution can be measured by X-ray radiography, and that this distribution is a very important parameter for the evaluation of the quality of cement plates reinforced with discontinuous mineral fibres.

Industrial Application of Radiographic Paper.
J.C. Domanus and P.A. Ruault, Materialprüfung 22 (1980) 111-117.

A comparison was made among high speed Kodak Industrex D X-ray film, Industrex Instant 600 and 620, and Agfa Gevaert Structurix IC radiographic papers. The quality of the radiographic image was tested by the use of standard and special IQI's as well as Al step wedges and artificial and natural defects. From the characteristic curves the speeds, contrasts and exposure latitudes were calculated. Exposure charts for aluminum were made. The quality of information available in the radiographs was analysed and the merits of the constant exposure technique stressed. Applications of paper radiography in the control of nuclear fuel elements, gas pipelines, castings, composite materials and other industrial items were described. Conclusions about information quality, sensitometric properties, equipment and fields of application of the radiographic paper were drawn.

Arbejdsrapport og vejledning vedrørende reparation af tre stk. vinger til 30 kW Riisagermølle (Working Report and Instruction for Repairing of Three Pieces of Wings from a 30 kW Riisager Mill.

J. Ethelfeld, F. Jensen, J. Kjøller and Aa. Lystrup, Risø-M-2207 (1980) 20 pp.

The report is an instruction for service and repair of the fibre glass wings.

User Manual for the Probabilistic Fuel Performance Code FRP.

J. Friis Jensen and I. Misfeldt, Risø-M-2257 (1980) 54 pp.

This report describes the use of the probabilistic fuel performance code FRP. Detailed descriptions of both input to and output from the program are given. The use of the program is illustrated by a sample case.

Hundreder af kilometer rør i kraftværker sikres ved streng kontrol (Strict Quality Control of Hundreds of Kilometers of Piping in Power Plants).

H.E. Gundtoft, Dansk Tekn. Tidsskrift 104, No. 10 (1980) 12-14.

The article describes the tube inspection system developed by the Department.

Recrystallization and Grain Growth of Multi-Phase and Particle Containing Materials.

N. Hansen, A.R. Jones and T. Leffers (editors), Proceedings of the 1st Risø International Symposium on Metallurgy and Materials Science, Risø, 8-12 September 1980. (Risø National Laboratory, Roskilde, 1980) 337 pp.

The presence of a distribution of particles in a material can have a decisive influence on the kinetics of recrystallization and grain growth and hence on the resulting microstructures. The papers of the symposium cover all the stages of the recrystallization process from the microstructure of the deformed state, through the nucleation of recrystallization, to the migration of high-angle boundaries during recrystallization and grain growth. A large number of papers deal with engineering materials; thus, an important objective of the symposium is fulfilled, viz. that of combining the fundamental and the applied aspects of the subject.

Additive Strengthening in Copper Alloys.

N. Hansen and P. Brøndsted, Res. Mech. 1 (1980) 197-213.

The yield stress and the flow stress in tension were determined at room temperature for a number of polycrystalline Cu-Al_2O_3 alloys.

Dispersion strengthening during the first 3% strain in polycrystalline Cu-Al_2O_3 alloys can be described on the basis of theories for the yield stress and flow stress of dispersion strengthened single crystals if a strength contribution due to matrix hardening is included. At intermediate strains (0.03-0.15) the stress-strain curves of the Cu-Al_2O_3 alloys are practically parallel to the curve for pure copper, i.e. the strengthening effect of particles is constant.

The grain boundary hardening in copper and in Cu-Al_2O_3 alloys can be described by a Petch-Hall relation, with slopes that are almost independent of the plastic strain, but increase when the particle spacing is decreased. An equation has been derived relating the changes in slope with particle spacing to changes in the yield stress of the Cu-Al_2O_3 alloys.

Solid solution strengthening can be added to dispersion strengthening and grain boundary hardening, resulting in thermally stable copper alloys with high strength and good electrical conductivity.

Thermal Analysis Studies of the Decomposition of Ammonium Uranyl Carbonate (AUC) under Simulated Industrial Conditions.

L. Hälldahl and O. Toft Sørensen, In: Thermal Analysis, Proceedings of the 6th International Conference on Thermal Analysis, Bayreuth, 6-12 July 1980. Edited by H.G. Wiedemann (Birkhaüser Verlag, Basel 1980) 499-504.

In a previous study (1) the decomposition and subsequent reduction of AUC were examined by conventional thermal analysis (TG and DTA) and the nature of the intermediate products formed during these processes in different atmospheres was established. A new series of measurements has been carried out in a modified thermobalance system in which the rapid heating of the AUC powders, characteristic of the industrial process, can be simulated. The equipment constructed for these measurements and the results obtained by this method in an actual industrial atmosphere are discussed in this paper.

Grain Boundary Migration Contrast in Thin Foils.

A. Horsewell, In: Electron Microscopy 1980, Proceedings of the 7th EUREM 80, The Hague, 24-29 August 1980. Vol. 1: Physics. Edited by P. Brederoo and G. Boom (Seventh European Congress on Electron Microscopy Foundation, Leiden, 1980) 236-237.

Migration of grain boundaries in their foils occurs frequently following foil production. The magnitude and direction of such migration may be inferred from bands of contrast produced adjacent to such boundaries.

Interfacial Structure of Epitaxial Gold on Platinum.

V.M. Ijevlev, S.B. Kuschev, K.S. Soloviev and A. Horsewell, In: Electron Microscopy 1980, Proceedings of the 7th EUREM 80, The Hague, 24-29 August 1980. Vol. 1: Physics. Edited by P. Brederoo and G. Boom (Seventh European Congress on Electron Microscopy Foundation, The Hague, 1980) 244-245.

While the epitaxial system Pt/(001)Au is well documented, Au/(001)Pt has been little studied. Reversal of misfit-stresses (tensile to compressive) has important consequences for growth mechanisms which are discussed.

Recovery Changes Leading to Nucleation of Recrystallization.

A.R. Jones and N. Hansen, In: Recrystallization and Grain Growth of Multi-Phase and Particle Containing Materials, Proceedings of the 1st Risø International Symposium on Metallurgy and Materials Science, Risø, 8-12 September 1980. Edited by N. Hansen, A.R. Jones and T. Leffers (Risø National Laboratory, Roskilde, 1980) 13-25.

The way in which distributions of small particles can affect deformation patterns and subsequent recovery leading to nucleation of recrystallisation is reviewed. As a comparison, general aspects of deformation and recovery behaviour in particle free materials are also considered. New data are presented on the nature of recovery changes occurring in Al-Al_2O_3 alloys. These data are presented with the specific intention of illustrating that the nature of particle related inhibition of recovery is more complex than has previously been thought. Aspects of recovery important to the subsequent development of nucleation of recrystallisation, but which are specific to low stacking fault energy alloy systems, are also illustrated and discussed.

Wingblades of Glass Fibre Reinforced Polyester for a 630 kW Windturbine - Design, Fabrication and Materials Testing.

B.S. Johansen, H. Lilholt and Aa. Lystrup, In: Advances in Composite Materials. Proceedings of the 3rd International Conference on Composite Materials, Paris, 26-29 August 1980. Edited by A.R. Bunsell, C. Bathias, A. Martrenchar, D. Menkes and G. Verchery (Pergamon Press, Oxford, 1980) 1355-1367.

Wingblades for a 630 kW windturbine are described. The conceptual design of the 20 m long wingblades comprises a load-bearing spar with aerodynamically shaped shells. The 12 m outer spar is made of highly directional glass fibres in a polyester matrix. The spar is fabricated by a special tape winding technique, which gives a high volume fraction of glass fibres oriented nearly parallel to the spar axis. Materials testing of the spar material and component testing of (sections of) the wingblade verify the properties of the glass-polyester laminate and the design of the wingblade.

Cutting of CFRP with Single Edge Tools.

A. Koplev, In: Advances in Composite Materials. Proceedings of the 3rd International Conference on Composite Materials, Paris, 26-29 August 1980. Edited by A.R. Bunsell, C. Bathias, A. Martrenchar, D. Menkes and G. Verchery (Pergamon Press, Oxford, 1980) 1597-1605.

The cutting process in the machining of carbon fibre-inforced plastics (cfrp) has been investigated. Cutting experiments have been carried out on unidirectional cfrp. The experiments involved orthogonal cutting of cfrp with a shaping machine and a 'quick-stop' machine.

A new method called 'macrochip' has been developed for ease of handling and investigation of the very small chips. The present work shows that the cutting process consists of a series of fractures, each releasing a small chip. This work presents a qualitative model for cutting parallel to the fibres, and discusses the thermodynamical relationships of the cutting process.

Spåntagende bearbejdning af kulfiber/epoxy komposit (En metallografisk undersøgelse af et brudfænomen). (Cutting of a Carbon Fibre/Epoxy Composite (A Metallographic Study of a Fracture Phenomenon)).

A. Koplev, In: Revner og brud (Cracks and Fracture). Dansk Metallurgisk Selskabs Vintermøde, Hindsgavl, 9-11 Januar 1980. Edited by E.W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1980) 371-381.

Useful information on cutting of materials can be deduced from investigation of the produced chips. In the case of carbon fibre composites and other brittle materials, this is very difficult because of the small chips. A new method, the "macrochip", makes the chips easy to handle and investigate. Together with the method, some experiments on cutting of carbon fibre composites are reported. They include the size and shape of the chips and the surface of the machined specimens.

On the Recombination Rate of Irradiation-Induced Interstitials and Vacancies.

T. Leffers and B.N. Singh, J. Nucl. Mater. 91 (1980) 336-342.

The rate of recombination of interstitials and vacancies is described on the basis of theoretically derived recombination cross-sections. The numerical values of these cross-sections are substantially lower than the values normally quoted in the literature. The physical situations behind the simplified recombination models (recombination between nearest-neighbour defects and recombination between defects with common nearest neighbours) and the transition between these situations are described. The consistency between the recombination term and the other rate-equation terms and the complications arising when interstitials and vacancies have approximately the same mobility are also discussed.

Teoretisk Styrke, Revner og Materialeegenskaber (Theoretical Strength, Cracks and Materials Properties).

H. Lilholt, In: Revner og Brud (Cracks and Fracture). Dansk Metallurgisk Selskabs Vintermøde, Hindsgavl, 9-11 januar 1980. Edited by E.W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1980) 7-17.

A brief survey is given of the theoretical strength of materials, cracks and dislocations, stress concentrations, and fracture energy.

Glass-Polyester Materials for a 20 m Rotorblade.

H. Lilholt, In: Implementary Agreement for Co-operation in the Development of Large Scale Wind Energy Conversion Systems. Fourth Meeting of Experts - Rotor Blade Technology with Special Respect to Fatigue Design Problems, Stockholm, 21-22 April 1980. Edited by E. Hav, S. Hugosson and R. Windheim (Kernforschungsanlage Jülich, 1980) (JÜL-SPEZ-82) 45-58.

The materials specifications, fabrication, materials testing and fatigue behaviour of glass-polyester for a rotorblade is described.

Belastning af glas-polyester-materialet i Nibe-vingerne under visse driftsforhold ("statiske") (Loads on the Glass-Polyester Material in the Nibe Wings under Certain Operational Conditions ("static")).

H. Lilholt, VK-Metal-7 (Energiministeriets og Elværkernes Vindkraftprogram) (1980) 9 pp.

Some loading situations for the Nibe windturbines were evaluated. The loadings are extreme cases, e.g. gale and oblique wind direction. The strains in the load bearing wingspars were calculated and compared with the materials properties.

Glass-Polyester Materials for a 20 m Rotorblade.

H. Lilholt, VK-Metal-9 (Energiministeriets og Elværkernes Vindkraftprogram) (1980) 14 pp.

The materials specification, fabrication, materials testing and fatigue behaviour of glass-polyester for a rotorblade is described.

Udmattelsesforhold i Materialet til Vinger (Fatigue Conditions in Wing Materials).

H. Lilholt, VK-Metal-10 (Energiministeriets og Elværkernes Vindkraftprogram) (1980) 3 pp.

Fatigue data were collected for several materials in practical use for wingblades for large windturbines: steel, aluminium, glass-polyester, glass-epoxy, carbon-epoxy, and wood.

Probabilistic Evaluation of Fuel Element Performance by the Combined Use of a Fast Running Simplistic and a Detailed Deterministic Fuel Performance Code.

I. Misfeldt, In: Specialists' Meeting on Fuel Element Performance Computer Modelling, Blackpool, 17-21 March 1980. (IAEA, Vienna, 1980) 244-251.

A comprehensive evaluation of fuel element performance requires a probabilistic fuel code supported by a well bench-marked deterministic code. This paper presents an analysis of a SGHWR ramp experiment, where the probabilistic fuel code FRP is utilized in combination with the deterministic fuel models FFRS and SLEUTH/SEER.

The statistical methods employed in FRP are Monto Carlo simulation or a low-order Taylor approximation. The fast-running simplistic fuel code FFRS is used for the deterministic simulations, whereas simulations with SLEUTH/SEER are used to verify the predictions of FFRS.

The ramp test was performed with a SGHWR fuel element, where 9 of the 36 fuel pins failed. There seemed to be good agreement between the deterministic simulations and the experiment, but the statistical evaluation shows that the uncertainty on the important performance parameters is too large for this "nice" result.

The analysis does therefore indicate a discrepancy between the experiment and the deterministic code predictions. Possible explanations for this disagreement are discussed.

SAP - Sintret aluminiumprodukt (SAP - Sintered Aluminium Products).

P. Nielsen, Svejsning 7, No. 6 (1980) 19-20.

The paper describes fabrication methods, properties and applications of sintered aluminium products. Special consideration is given to applications as materials for light weight pistons in diesel engines.

Spændingskorrosion i austenitiske rustfrie stål (Stress Corrosion in Austenitic Stainless Steel).

T.S. Nielsen, In: Revner og Brud (Cracks and Fracture). Dansk Metallurgisk Selskabs Vintermøde, Hindsgavl, 9-11 Januar 1980. Edited by E.W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1980) 165-182.

The environments that are known to produce stress corrosion cracks in austenitic stainless steels are reviewed with special emphasis on chloride solutions, caustic solutions and hot, oxygen-containing water. The proposed mechanisms are presented, and the more specific boundaries for the occurrence of cracking are described. Especially the lack of engineering guidelines is underlined.

Behaviour of Hard and Soft Ions in Solid Electrolytes.
F.W. Poulsen, In: Materials for Advanced Batteries. Proceedings of a NATO Symposium, Aussois, 9-14 September 1979. Edited by D.W. Murphy, J. Broadhead and B.C.H. Steele (Plenum Press, New York, 1980) 229-233.

Single crystals and polycrystals of pure copper were fatigued in tension-compression at constant low amplitudes of plastic strain and low cycling frequencies at room temperature in air. Surface patterns of persistent slip bands were quantitatively examined by optical microscopy. Bulk dislocation microstructures were examined by transmission electron microscopy. The microstructure and mechanical behaviour observed for the single crystals are in close quantitative agreement with comparable existing fatigue data. The cyclic stress-strain curve of the polycrystals shows a plateau in a linear plot of the saturation stress versus the plastic strain amplitude. The area fraction of PSB's on the polycrystals increases roughly linearly with the plastic strain amplitude. The dislocation microstructure in bulk grains consists of regular wall structures embedded in a matrix of less regular structures. A Sachs type model in which the small plastic strain incompatibility caused by bulk persistent slip is elastically accommodated is consistent with the experimental observations.

Raman Study of New Addition Compounds of SCl_4.
F.W. Poulsen, Inorg. Nucl. Chem. Lett. 16 (1980) 355-360.

This report describes fuel cell - and other possible applications of solid proton conductors. The best performing materials known today are listed. Typical synthetic routes and some models for proton transport in solids are discussed. Hints to future research are given.

An Introduction to Proton Conduction in Solids.
F.W. Poulsen, Risø-M-2244 (1980) 23 pp.

Four new compounds have been synthesized and characterized by Raman spectroscopy during this study: $[SCl_3^+, GaCl_4^-]$, $SCl_3^+, InCl_4^-]$, $[SCl_3^+, TeCl_5^-]$, and $[2SCl_3^+, ZrCl_6^{2-}]$. The materials were made by reaction of sulfur, the parent metal chloride and liquid chlorine. They are highly oxidizing compounds.

Fatigue of Copper Polycrystals at Low Plastic Strain Amplitudes.
K.V. Rasmussen and O.B. Pedersen, Acta Met. 28 (1980) 1467-1478.

The abstract appeared in the previous progress report p. 67.

Experience with Nitriding of Austenitic Stainless Steel and Inconel in Ammonia Environments.

K. Rørbo, In: Environmental Degradation of High Temperature Materials. Proceedings of the Spring Residential Conference, Isle of Man, 31 March - 3 April 1980, Vol. 2. (The Institution of Metallurgists, London, 1980) (Spring Residential Conference Series 3, Vol. 2, No. 13, 1980) P/47-P/53.

Experience with nitriding of AISI 304 stainless steel and Inconel 600 components in ammonia converters with operating times of from four to eight years is given. The average nitriding rates observed are for austenitic stainless steel typically in the range of 10-100 µm/y. The results of laboratory scale experiments on the nitriding behaviour of austenitic stainless steel and of Inconel 600 and Inconel 625 in pure ammonia at 700°C are given.

Corrosion Aspects of High-Level Waste Disposal in Salt Domes.

K. Rørbo, Report (1980) 37 pp.

The report has been worked out according to the agreement between Risø National Laboratory and ELSAM/ELKRAFT concerning advisory assistance from Risø to ELSAM/ELKRAFT's waste management project, phase 2. The report was declassified by ELSAM/ELKRAFT December 1980.

The corrosion behaviour of a number of candidate materials for canisters for glassified high-level radioactive waste in salt domes is discussed. It is concluded that due to the limited amount of brine available a thick-walled steel canister will have a satisfactory life time. Also the possible improvement obtained by using a double-walled canister (steel plus a more noble metal) is discussed.

The Effect of Vacuum Environment on Void Formation during HVEM Irradiation.

B.N. Singh and T. Leffers, In: Electronmicroscopy 1980. Proceedings of the 6th International Conference on High Voltage Electron Microscopy, Antwerp, 1-3 September 1980, Vol. 4, High Voltage. Edited by P. Brederoo and J. van Landuyt (7th European Congress on Electron Microscopy Foundation, Leiden, 1980) 262-265.

High-purity copper specimens have been irradiated in different vacuum environment in a High Voltage Electron Microscope at temperatures in the range 250-450°C. It is found that decreasing pressure makes void formation increasingly difficult or impossible in annealed specimens whereas it has no noticeable effect in cold-worked specimens. The results are interpreted in terms of untrapped gas atoms during irradiation.

Energy-Dispersive X-ray Diffraction Studies of the Texture in Cold-Rolled Alpha-Beta Brass.

J. Szpunar and L. Gerward, J. Mater. Sci. 15 (1980) 469-476.

It is shown tnat energy-dispersive X-ray diffraction can be used for simultaneous measurement of several pole figures and that the accuracy is sufficient for the determination of the crystallite orientation distribution. The method is applied to the study of the texture in Cu-43 wt% Zn duplex alpha-beta brass rolled to 80% reduction.

Densification Studies of Ceramic Powder Compacts by Quasi-Isothermal Dilatometry.

O. Toft Sørensen, In: Thermal Analysis. Proceedings of the 6th International Conference on Thermal Analysis, Bayreuth, 6-12 July 1980. Edited by H.G. Wiedemann (Birkhaüser Verlag, Basel, 1980) 231-236.

We present a simple procedure for measuring the changes in stiffness properties of a unidirectional fibrous composite caused by fatigue damage. Unlike previous attempts at stiffness-based fatigue damage characterization, where one or two elastic constants have been investigated, we consider changes in all four independent stiffness constants of an orthotropic elastic lamina. The results obtained for a unidirectional glass fibre reinforced polyester show that while small changes occur in the longitudinal elastic modulus and the Poisson's ratio of transverse to longitudinal strains, the shear modulus and the Poisson's ratio of longitudinal to transverse strains change significantly.

Stiffness Based Fatigue Damage Characterization of Fibrous Composites.

R. Talreja, In: Advances in Composite Materials. Proceedings of the 3rd International Conference on Composite Materials, Paris, 26-29 August 1980. Edited by A.R. Bunsell, C. Bathias, A. Martrenchar, D. Menkes and G. Verchery (Pergamon Press, Oxford, 1980) 1732-1739.

The concepts involved in the risk analysis of structures subjected to failure are reviewed. An approach based on fracture mechanics principles for calculating the probability of failure is described. The application of this approach to the selection of materials to minimize the risk of failure is then discussed for a few practical situations.

Materialeegenskabernes betydning for risikoanalyse (The Role of Materials Properties in Risk Analysis).

R. Talreja, In: Revner og Brud (Cracks and Fracture). Dansk Metallurgisk Selskabs Vintermøde, Hindsgavl, 9-11 Januar 1980. Edited by E.W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1980) 502-513.

Quasi-isothermal dilatometry (QID) is a new technique which can be used with great advantage in sintering studies of powder compacts. Contrary to conventional dilatometric measurements the optimum heating rate can be determined in a single run by this technique and from the measured shrinkage curve the controlling sintering mechanism and its activation energy can be determined. In this paper the advantage of this method is demonstrated and a method is given for calculating the activation energies from the QID curves. As an example the curves obtained in sintering studies of CeO_2-Gd_2O_3 compacts are analysed and the kinetic data for the different stages involved in the sintering are determined.

Magnesium for Hydrogen Storage.

B. Vigeholm, J. Kjøller and B. Larsen, In: Metal Hydrides 1980. Proceedings of the International Symposium on the Properties and Applications of Metal Hydrides, Colerado Springs, 4-7 April 1980, Vol. 2. Edited by G. Libowitz and G.D. Sandrock (Elsevier, Lausanne, 1980) 341-350. (Also in J. Less-Common Metals 74 (1980) 341-350).

The reaction of hydrogen with commercially pure magnesium powder (above 99.7%) was investigated in the temperature range 250-400°C. Hydrogen is readily sorbed above the dissociation pressure. During the initial exposure the magnesium powder sorbs hydrogen slowly below 400°C but during the second exposure the sorption is fast from about 250°C and is nearly completed when 400°C is reached after 10 min; no change in the sorption rate is observed with further cycling. In most experiments the resultant hydride is close to stoichiometric MgH_2. Desorption is found to be slower and to require higher temperatures than sorption but is still practicable. Comparisons of powders with particle sizes ranging from less than 37 μm to more than 500 μm indicate that the specific surface area is the rate-determining factor. Scanning electron micrographs show that after sorption the particles become spongy. The fact that the particles do not disintegrate is explained by a sintering process at the working temperatures. Exposure to air does not impair the sorption ability; on the contrary, it appears that surface oxidation plays an important role in the reaction. Some handling problems, e.g. the reaction of the hydride with water vapour in air of normal humidity, were also investigated.

Hydrogen Storage in Magnesium Powder.

B. Vigeholm, J. Kjøller and B. Larsen, Powder Met. Int. 12 (1980) 136-137.

A high pressure facility allowed to study the reaction of hydrogen with magnesium powder. Immediate reaction leading to MgH_2 took place. It was found that no pretreatment of the powder is needed, that surface oxidation has no harmful effect, that the reaction starts at 250°C and is completed at 4 MPa after 15 min.

Microstructure of WC/Co Cemented Carbide.

S. Vuorinen and A. Horsewell, In: Electron Microscopy 1980. Proceedings of the 7th EUREM 80, The Hague, 24-29 August 1980, Vol. 1: Physics. Edited by P. Brederoo and G. Boom (Seventh European Congress on Electron Microscopy Foundation, Leiden, 1980) 420-421.

TEM observation of deformed and undeformed WC/Co hard metals reveals few networks of dislocations in the carbide, transformation stacking faults in the binder and deformation in the WC/WC grain boundaries. The latter indicates incomplete binder wetting during liquid phase sintering.

A TEM Study of Titanium Carbide Coating on Hard Metal.

S. Vuorinen and A. Horsewell, In: Proceedings of the 3rd European Conference on Chemical Vapour Deposition, Neuchatel, 16-18 April 1980. Edited by H.E. Hintermann (Laboratoire Suisse de Recherches Horlogeres, Neuchatel, 1980) 117-122.

TiC coatings by CUD on WC/Co hard metals have been examined by TEM. Microstructural variations with coating thickness are found to be a function of crystallographic and chemical differences in the inhomogeneous substrate.

LECTURES

Computer Based Recording and Handling of Non-Destructive PIE Data at Risø.

C. Bagger, presented at the Meeting on Post Irradiation Examination, Granges-over-Sands, 13-15 May 1980. (Proceedings to be published).

A computer-based data acquisition and handling system for gamma and dimensional measurements has been in service since 1976. The system which at present is being extended to other post-irradiation examination fields such as eddy current testing has increased the amount of raw data acquired considerably, but quick and efficient methods of storage and filtering of data has decreased the time necessary for evaluation of experiments.

The general reliability of the measurements has been increased by introducing routine quality control procedures in the data sampling programme.

Further improvement of reliability has been obtained by use of precise positioning devices allowing repetition of measurement series with intermittent recalibration of measuring equipment.

The computer-based acquisition of gamma- and dimensional measurements together with the subsequent handling of resulting data is described.

Equipment for Mechanical Piercing and Free Volume Determination.

H. Carlsen, presented at the Meeting on Post Irradiation Examination, Granges-over-Sands, 13-15 May 1980. (Proceedings to be published).

New equipment has been constructed for the piercing of irradiated fuel pins and the determination of the free volume in the pins. The attainment of tightness, especially between the equipment and the pin, and of a small dead volume is described.

Avancerede loddemetoder (Advanced Soldering Methods).

J. Christensen, presented at Svejsecentralen, Glostrup, 20 February 1980 (Not available).

After a short introduction where mechanized flame- and induction brazing were mentioned, there was given a more detailed description together with the prospects of fluxless brazing processes: copper brazing in continuous hydrogen furnaces, high vacuum brazing of stainless steels, high temperature alloys and aluminium and ultrasonic soldering. The importance of the influence of design and brazing filler metal selection on the mechanical properties of the brazed joint and on the total economy of the brazed products was emphasized and exemplified.

Acoustic Emission from Structural Steels and Weldments.
C.P. Debel, P. Krarup, A. Nielsen, H.E. Hjelmroth and N.E. Swindlehurst, presented at the Conference on Elastic Waves and Microstructure, Oxford, 16-17 December 1980 (to appear in Metal Science).

Acoustic emission (AE) burst signals generated by deformation and fracture processes associated with crack growth under monotonic loading of two types of structural steels and three types of weldments have been measured under various testing conditions, with attention paid to burst signals sufficiently large to be used during surveillance.

A mild C-Mn steel and a Nb-microalloyed and Al-treated C-Mn steel, both normalised, were studied. Weld metals were produced by submerged arc welding, manual welding and CO_2 welding. The weldments were studied in the as welded as well as in the post-weld heat-treated condition. A single channel AE monitoring system was applied during tests of notched specimens and medium sized pressure vessels.

The two base metals generated only a small amount of AE burst signals under all testing conditions whereas the number of burst signals generated by some of the weld metals was considerably larger. The number of burst signals increased when the temperature decreased into the toughness transition temperature region. The AE activity of the weld metals during fracture seems associated with a particular fracture mode involving microcleavage.

No usable AE was generated by the base metals during pressure vessel tests to failure, whereas the testing of vessels with an experimental weld did result in the recording of some AE.

The Need for Standardization in the Field of Neutron Radiography.
J.C. Domanus, presented at the Meeting on Post Irradiation Examination, Granges-over-Sands, 13-15 May 1980. (Proceedings to be published).

Like in other fields on industrial radiography, in neutron radiography of nuclear fuel, standardization is necessary to be able to use recognized methods for the control of radiographic image quality as well as procedures which will assure that the prescribed quality can be obtained. Having this in mind standardization work was initiated within Euratom to cope with the different problems of neutron radiography of nuclear fuel elements. Present status of work in this field is reviewed.

Recrystallization Kinetics in High Purity Copper Studied by Neutron Diffraction.

N. Hansen, T. Leffers and J.K. Kjems, presented at the Journées Metallurgique d'Automne, Paris, 27-30 October 1980 (to appear in Acta Met.).

The potential of neutron-diffraction texture measurement as a tool for accurate investigations of recrystallization kinetics is demonstrated by the application of the method to the recrystallization of heavily rolled copper (99.98% purity). The present investigation demonstrates that this technique compares favourably with the standard methods in this field, and it is argued that there is scope for substantial improvements. The results are interpreted in terms of an Avrami equation, and it is suggested that the recrystallization kinetics for the texture components monitored are determined by nucleation and not by growth. The microstructural evolution during recrystallization as studied by light microscopy supports this interpretation.

Karakterisering af faststofionlederen $LiI \cdot D_2O$ (Characterization of the Solid State Ion Conductor $LiI \cdot D_2O$).

N. Hessel Andersen and F. Krebs Larsen, presented at 16. Danske Krystallografmøde, Århus, 22 May 1980. (Not available).

In the last years the technological aspects in an all solid state battery have increased the interest for studying the properties of solid ionic conductors. The desire of low weight batteries for use in vehicles has focused on compounds with Li-ions as moving species but also the abundance and the high theoretical upper limit for the conductivity of Li-ions have contributed.

Among the so far known Li-ionic conductors, $LiI \cdot H_2O$ (D_2O) has one of the highest conductivities: $6 \times 10^{-6}\ \Omega^{-1}cm^{-1}$ at room temperature and $4 \times 10^{-3}\ \Omega^{-1}cm^{-1}$ at 120°C. In contrast to the usual behaviour of solid ionic conductors there has been no observation of a phase transition in connection with the appearance of the high conductivity. The crystal structure (space group Pm3m) has built in more Li-positions than Li-ions which allow for Li-diffusion through the lattice. In the study of the mechanisms which promote the high ionic conductivity it is important to know the positions and the dynamic properties of the Li-ions. The present neutron diffraction investigation on single crystalline $LiI \cdot D_2O$ has been performed in order to study the positions of the Li-ions in the lattice and the orientation of the D_2O-molecule.

The Expected Improvement in Power Ramp Performance from the Use of Duplex Fuel.

D.A. Howl, D.N. Coucill and I. Misfeldt, presented at the Enlarged Halden Programme Group Meeting, Lillehammer, 1-6 June 1980. (Not available).

A joint exercise by BNFL, Risø and the UKAEA has been completed in which the production cost penalties and the benefits from improved operating performance have been estimated. The exercise used the Danish LOWI design as an example of duplex fuel, and the evaluation was made for a typical 17 × 17 PWR. Both UK and Danish fuel performance codes were used to determine the improvement in power ramp performance compared with that of standard solid fuel. The results from this part of the exercise are outlined in the present paper.

The results of this theoretical evaluation encourage the belief that the use of an optimised duplex fuel design would reduce power ramp failures sufficiently to allow the operating restrictions (due to fuel considerations) which are currently used in a PWR to be largely relaxed. The benefit from duplex fuel is shown to decrease with increasing burn-up, but is insensitive to the mean fuel enrichment. The greatest improvements are predicted for the thinnest enriched rings, within the range evaluated.

Important input data for the calculations were the radial power profiles in the fuels, and the variations of these profiles with burn-up. These data were obtained by reactor physics calculations made by the UKAEA, and are briefly referred to in the present paper.

Overview of Risø Fission Gas Project.

P. Knudsen, presented at the DOE/EPRI Contractor's Meeting, Atlanta, 8-9 April 1980. (Transcript available, 8 pp.).

The objective of this project is to provide well-characterized experimental data on fission gas release and other aspects of the high-burnup performance of water reactor fuel. The project is sponsored internationally by fuel suppliers, electric utilities and nuclear safety and research organizations.

UO_2-Zr fuel were previously irradiated to peak pellet burn-ups exceeding 40,000 MWD/tU. Most of these fuel pins are subjected to a short re-irradiation in the DR3 reactor at Risø, in order to simulate postulated power increases late in life for power reactor fuel. Extensive examinations in the Risø hot cells include fission gas measurements, fuel characterizations etc. The project period is 1980-81.

Power Ramp Performance of Vipac Fuel.

P. Knudsen, C. Bagger and H. Carlsen, presented at the IAEA Specialists' Meeting on Pellet Cladding Interaction in Water Reactors, Risø, 22-26 September 1980. (Proceedings to be published).

Vibrationally compacted powder fuel ("vipac") may conceivably perform better than sintered pellet fuel in power ramp situations, because the smaller fuel particles may give less stress concentrations in the cladding at hard fuel-clad contact. It is, therefore, of interest to examine experimentally the power ramp performance of vipac fuel.

Four Zircaloy-clad vipac pins and one pellet pin were ramp tested at a burn-up of 17,900 MWD/t UO_2. Three of the vipac pins failed in fast ramps at peak heat loads of 411-459 W/cm and the pellet pin failed at 348 W/cm. The fourth vipac pin was conditioned at 379 W/cm for 2 days; with a slow ramp rate of 5 W/cm·min, an overpower level of 528 W/cm was reached without failure indication.

An evaluation of the local overpower levels and the eddy-current observations showed that the vipac pins had an advantage of about 80 W/cm over the pellet pin in terms of minimum heat load required for interaction and defection. The many cladding cracks seen in one of the failed vipac pins had the usual brittle appearance attributed to stress-corrosion cracking.

Værktøjsslid ved Spåntagning af kulfiberkomposit (Wear of Tools in Machining of Carbon-Fibre Composite).

A. Koplev, presented at AMT's Emnedag om Tribologi, Lyngby, 26 February 1980. (Resume published in AMT Publication MM 80 21 A (1980) 60-65).

The tool wear when machining carbon fibre composites is very large. The composites wear the tools in quite another manner than metals do. The reasons may be found in the physical and mechanical properties of the fibres, and in the thermodynamical circumstances of the machining process.

The Use of Probabilistic Fuel Performance Codes in the Planning and Evaluation of Irradiation Experiments.

I. Misfeldt, presented at the IAEA Specialists' Meeting on Pellet Cladding Interaction in Water Reactors, Risø, 22-26 September 1980. (Proceedings to be published).

As well in the planning as in the evaluation of fuel experiments it is important to know the influence on the test results from the uncertainties (tolerances) of design parameters, material properties and test specifications. This information can be obtained by a probabilistic fuel performance code like PRP.

A fuel performance code simulates detailed processes which take place during the irradiation, and therefore the use of a code requires detailed information on the fuel and the irradiation. The present paper details these requirements and discusses the influence on the expected fuel performance from the most important specifications required.

Examples are given of the evaluation of performed ramp tests, especially with regard to the expected uncertainties on the test results.

Analysis of Selected Halden Experiments with the Danish Fuel Performance Codes.

I. Misfeldt and J. Friis Jensen, presented at the Enlarged Halden Programme Group Meeting, Lillehammer, 1-6 June 1980. (Not available).

Several IFA experiments are analysed with the Danish fuel performance codes FRP and WAFER. The measured centre temperature during the start-up ramps is compared with the code predictions for pins with varying fill gas composition and gap sizes. The effect of densification, hot swelling and relocation is studied by means of the measured centre temperature during the first irradiation period.

Metalhydrid som energibærer (Metal Hydride as an Energy Carrier).

A. Schrøder Pedersen, presented to Kemisk Forening, Copenhagen, 30 October 1980. (Not available).

Increasing efforts have been seen to find and develop systems, which facilitate a more efficient and economic use of energy sources. One candidate system is the metal-hydrogen system. Numerous metals and alloys react with hydrogen to form metal hydrides, which dissociate when heated. Many of these have to be disregarded for different reasons (e.g. slow kinetics, too high enthalpy of reaction, inconvenient temperature-pressure relations).

In the talk some characteristics and applications of metal hydrides were presented with special reference to compounds of Mg and FeTi.

Fatigue of Composite Materials.

R. Talreja, presented at Nordisk Forskerkursus i Fiberkompositter, Linköping, 1-8 September 1980. (Not available).

The basic fatigue damage mechanisms in composite laminates are reviewed. Based on these mechanisms, a pattern in the fatigue life diagrams is proposed. Several experimental data are shown to agree with this basic pattern. Fatigue ratio is defined in terms of strains and fatigue limit is shown to exist for unidirectional, cross-plied and angle-plied laminates. The limitations to the fatigue performance of composite laminates are pointed out and suggestions for improving it are made.

Fatigue of Composite Materials: Damage Mechanisms and Fatigue Life Diagrams.

R. Talreja, presented at the Conference on Fracture and Fatigue of Composite Materials, Linköping, 4 September 1980. (Not available).

Fatigue damage mechanisms in composite laminates of different fibre orientations subjected to tension, compression, bending and torsion were reviewed. The characterization of fatigue damage based on changes in stiffness properties was described. The role of limiting fatigue strains in design of composite components was discussed.

Brint i Fremtidens Energiforsyning (Hydrogen in Energy Supply in the Future).

B. Vigeholm, presented to The Rotary Club, Roskilde, 9 January 1980. (Not available).

Energy storage is a means of improving the efficiency of conventional power plants as well as the utilization of new intermittent sources. Except for water dams no storage system has uptil now been economical. Among the many systems being investigated these years, metal hydrides is a promising example which links the very flexible non-polluting energy vector hydrogen to high density storage of chemical energy.

The concept and the state of the art is described in general terms. A number of representative applications, e.g. fuel tanks in land vehicles, are explained. Finally the research in progress at Risø, concentrated on Mg-based hydride systems, is outlined.

Metalhydrider - Fremtidens Energilagring? (Metal Hydrides - The Method of Energy Storage of the Future?).

B. Vigeholm, presented to Jysk Selskab for Kemi og Fysik, Århus Universitet, 13 November 1980. (Not available).

Review of hydrogen as an energy vector with emphasis on applications associated with hydrogen stored in metal systems.

STAFF OF THE DEPARTMENT

(as at 31 December, 1980)

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1) Employee from the Elsinore Shipyard Ltd.
2) Post-graduate student from the Technical University of Denmark
3) Post-graduate student from the University of Copenhagen
4) IAEA stipendiate

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